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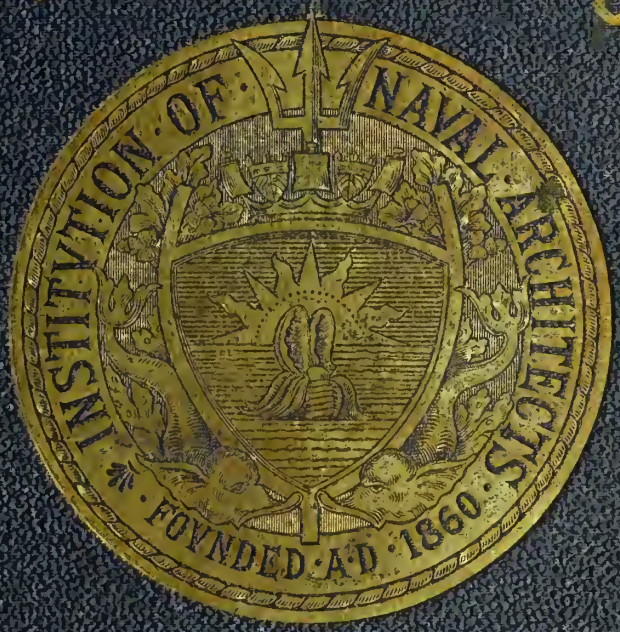

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Errata.

Page viii, Mr. William Paulsen's name should not appear in the List of Members.

Page 187, line 23, for steam boilers *read* steel boilers.

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Sewell, F. D., Captain.
Shadwell, Sir Charles F. A., C.B., Vice-Admiral.
Siemens, Charles W., F.R.S., D.C.L.
Sinnette, George Mathias.
Small, Thomas.
Smith, The Right Hon. W. H., M.P. (Vice-President).
Smith, Charles William.
Smith, G. Fereday, M.A., J.P.
Smith, John.
Smith, Josiah T.
Smith, Wasteneys, C.E.
Smyth-Pigott, J. H. W., J.P., D.L.
Spence, James Carmichael
Spyer, Arthur.
Stewart, John.
Stewart, Sir W. Houston, K.C.B., Vice-Admiral (Vice-President).
Stothert, G. K.

Sudely, The Right Hon. Lord.
Suffield, Thomas.
Swinburne, Thomas A., Captain, R.N.
Symington, William, Captain.
Symonds, Thomas E., Captain, R.N. (Assoc. Mem. Council).

Talbot, Edward.
Talbot, Edward James
Talbot, J. William.
Testa, Charles, Captain, Royal Portuguese Navy.
Thompson, E.
Thomson, Andrew.
Thornycroft, John Isaac, C.E.
Thurston, Robert H., C.E.
Tindall, William H.
Tough, R. T.
Tryon, George, C.B., Captain, R.N.

Van der Made, D. J. P.
Varvelli, G. Marino.

Waddilove, Charles L., Rear-Admiral.
Waltjen, Charles.
Warren, Alfred.
Watson, William.
Westhorp, Theophilus.
Wheatley, William Coe.
Wheeler, Joseph, junr.
Whyham, Maurice.
Williams, George, Rear-Admiral.
Williams, Samuel.
Williamson, R. H.
Wilson, Archibald.
Wise, William Lloyd.
Wood, George.
Wood, George E.
Woodhouse, John T.
Woolfe, J. S.
Woolley, Joseph, M.A., LL.D., (Vice-President).

Yeo, John, Engineer, R.N.

Zeysing, Theodore, Prussian Royal Navy.

OBJECTS OF THE INSTITUTION.

The objects of the Institution of Naval Architects—which was established to promote the Improvement of Ships, and of all that specially appertains to them—are comprised under three heads :—

First, the bringing together of those results of experience which so many shipbuilders, marine engineers, naval officers, yachtsmen, and others acquire, independently of each other, in various parts of the country, and which, though almost valueless when unconnected, doubtless tend much to improve our navies when brought together in the printed Transactions of an Institution.

Secondly, the carrying out, by the collective agency of the Institution, of such experimental and other enquiries as may be deemed essential to the promotion of the science and art of shipbuilding, but are of too great magnitude for private persons to undertake individually.

Thirdly, the examination of new inventions, and the investigation of those professional questions which often arise, and were left undecided before the establishment of this Institution, because no public body to which professional reference could be made then existed.

BYE-LAWS AND REGULATIONS.

CONSTITUTION.

1. The Institution of Naval Architects shall consist of four classes, *viz.*, Members, Associates, Honorary Members, and Honorary Associates.

2. *Members.*—The Class of Members shall consist exclusively of Naval Architects and Marine Engineers conversant with Naval Architecture.

3. *Associates.*—The Class of Associates shall consist of persons who are qualified, either by profession or occupation, or by scientific or other attainments, to discuss with Naval Architects the qualities of a ship, or the construction, manufacture, or arrangement of some part or parts of a ship or her equipment.

4. *Honorary Members.*—The Class of Honorary Members shall consist of persons who are eligible as Members, and upon whom the Council may see fit to confer an honorary distinction.

5. *Honorary Associates.*—The Class of Honorary Associates shall consist of persons who have contributed to the improvement of ships or their equipment, and upon whom the Council may see fit to confer an honorary distinction.

ELECTION AND DUTIES OF OFFICERS.

6. The Officers of the Institution shall consist of a President, Vice-Presidents, Members of Council, Associate Members of Council (not exceeding in number one-third the number of Members of Council), a Treasurer, two Auditors of Accounts, and a Secretary or Secretaries.

7. A General Meeting of the Members and Associates of the Institution shall be held annually; and at this Annual General Meeting the Members of Council, Associate Members of Council, Treasurer, and Auditors for the ensuing year shall be elected.

8. At the Annual General Meeting Members only shall vote in the Election of Members of Council, and both Associates and Members in the Election of Associate Members of Council, the Treasurer and the Auditors.

9. As soon as may be convenient after the Annual General Meeting, the newly-elected Members and Associate Members of Council shall meet and elect the President and Vice-Presidents for the year, Members and Associate Members of Council both voting.

10. *President.*—Both Members and Associates of the Institution shall be eligible for election as President. The President shall preside over all Meetings of the Institution, and of Officers of the Institution, at which he is present, and shall regulate and keep order in the proceedings.

11. *Vice-Presidents.*—Both Members and Associates of the Institution shall be eligible for election as Vice-Presidents. In the absence of the President, one of the Vice-Presidents shall preside at the General Meetings of the Institution, and shall regulate and keep order in the proceedings.

12. In case of the absence of the President and of all the Vice-Presidents, the Meeting may elect any Member of Council or Associate Member of Council, and in case of their absence any Member present, to preside.

13. The Chairman at any Meeting of the Council or of the Institution, when the votes of the Meeting, including his own, are equally divided, shall be entitled to give a casting vote.

14. Persons holding the office of Vice-President shall at all times be entitled to sit and vote with the Council.

15. *Past Presidents and Vice-Presidents.*—All Members who have held the posts of President and Vice-President shall, while their connection with the Institution as Members lasts, be entitled to sit and vote with the Members of Council.

16. *Members of Council.*—Members only shall be eligible for Election as Members of Council at the Annual General Meeting.

17. *Associate Members of Council.*—Associates only shall be eligible for Election as Associate Members of Council at the Annual General Meeting.

18. The Direction and Management of the Institution shall be vested in the Council for the time being, the Associate Members voting with the Members of Council in all cases, except in the decision of questions directly affecting the forms of ships and the construction of their hulls.

19. The Council shall meet as often as the business of the Institution requires, and at every Meeting five Members of Council shall form a *quorum*.

20. The Council may appoint Committees to report to them upon special subjects.

21. All questions shall be decided in the Council by vote; but at the desire, expressed in writing, of any four Members or Associate Members present, the determination of any subject shall be postponed to the succeeding Meeting of the Council.

22. An annual statement of the funds of the Institution, and of the receipts and payments of the past year, shall be made under the direction of the Council, and after having been verified and signed by the Auditors, shall be laid before the Annual General Meeting.

23. The Council shall draw up an Annual Report on the state of the Institution, which shall be read at the Annual General Meeting.

24. It shall be the duty of the Council to adopt every possible means of advancing the Institution, to provide

for properly conducting its business in all cases of emergency, such as the death or resignation of Officers, and to arrange for the publication of the Papers read at the Meetings, or of such documents as may be calculated to advance the objects of the Institution.

25. *Treasurer.*—Only Bankers, or Members of Council, or persons who have been Members of Council, and are still Members of the Institution, shall be eligible for election as Treasurer.

26. *Auditors.*—All Members and Associates of the Institution shall be eligible for election as Auditors.

27. The Auditors shall have access at all reasonable times to the Accounts of the pecuniary transactions of the Institution; and they shall examine and sign the annual statement of the Accounts before it is submitted by the Council to the Annual General Meeting.

28. *Secretary.*—The Secretary or Secretaries shall be elected by the Council, and shall be removable at the will of the Council, after due notice given. The salary of the Secretary or Secretaries shall be fixed by the Council.

29. It shall be the duty of the Secretary, under the direction of the Council, to conduct the correspondence of the Institution; to attend all Meetings of the Institution and of the Council; to take Minutes of the proceedings of such Meetings; to read the Minutes of the preceding Meeting; to announce donations made to the Institution; to superintend the publication of such Papers as the Council may direct; to have charge of the library, museum, and offices of the Institution; and to direct the collection of subscriptions and the preparation of accounts. He shall also engage, and be responsible for, all persons employed under him, and generally conduct the ordinary business of the Institution.

DESIGNATION OF MEMBERS AND ASSOCIATES.

30. Any Member, Associate, Honorary Member, or Honorary Associate, having occasion to designate himself as belonging to the Institution, shall state the class to which he belongs according to the following abbreviated forms, *viz.*: M.I.N.A.; Assoc. I.N.A.; Hon. Mem. I.N.A.; Hon. Assoc. I.N.A.

ELECTION OF MEMBERS AND ASSOCIATES.

31. *Admission of Members.*—Every Candidate for admission into the Class of Members, or for transfer into that Class from the Class of Associates, shall be more than twenty-five years of age, and shall comply with the following Regulation:—

> He shall submit to the Council a statement, showing that he has been professionally engaged in shipbuilding or marine engineering for at least seven years in some public or private shipbuilding establishment, or marine engine works, and setting forth the grounds upon which he bases his claims to be considered a professional Naval Architect, or Marine Engineer, and to be admitted as such to the Membership of the Institution. This shall be signed by at least three Members, whose signatures shall certify their personal knowledge of the Candidate, and approval of his statement; or, in the case of persons not British born, the signatures of three Members shall be required, in confirmation of their personal knowledge of the Candidate's scientific reputation.

32. These preliminary conditions being satisfied, the Council shall then consider whether the practical experience and professional attainments of the Candidate are such as entitle him to be brought forward by the Council as a Naval Architect, or Marine Engineer conversant with Naval Architecture. If four-fifths at least of the received votes of the professional Members of the Council are in favour of his application, and such four-fifths constitute a majority of the professional Members of the Council, his proposal for admission shall be

submitted to the Members of the Institution (who shall have access to the applicant's statement) at an Ordinary Meeting of the Institution, for them to vote upon, by ballot.

33. *Admission of Associates.*—Candidates for Associateship shall submit to the Council a proposal for their admission, setting forth therein a statement of their claims to be admitted as Associates. Their proposal, if approved by the Council, shall be submitted by them at an Ordinary Meeting of the Institution, for the Members and Associates jointly to vote upon by ballot.

34. The proportion of votes for deciding the election of Members and Associates shall be at least four-fifths of the numbers recorded.

SUBSCRIPTIONS.

35. Each Member and Associate shall pay an Entrance Fee of two guineas and an Annual Subscription of two guineas in advance; the first Subscription being payable on his election, and all future ones on the 1st day of January of each year. Any Member or Associate withdrawing from the Institution after that date is still liable for the amount of Subscription due on that day.

36. Any Member or Associate may compound for his Annual Subscription, for life, by a single payment of not less than thirty guineas.

37. No person's name shall be entered on the Roll as Member or Associate of the Institution nor possess the privileges of Membership (except it be on the honorary list) until he shall have paid his first subscription or the life composition, and if the payment be delayed for more than twelve months from the date of his election, the same shall be void unless the Council otherwise direct.

38. The Secretary shall at the close of every year notify to all Members and Associates whose subscription for that year shall not have been paid, that it will be his duty to report accordingly to the Council, and he shall at the same time furnish the person whose subscription is in arrear with copies of this and of the two following Rules.

39. The Secretary shall before Easter in every year lay before the Council a list of all Members and Associates whose subscriptions for the two previous years shall be still unpaid, and unless the Council shall otherwise direct the names of those in arrear shall be expunged from the Roll of Members and Associates, and shall not be replaced without re-election in due form. Provided always that the Council shall at any time within two years therefrom have power to dispense with such re-election, and to restore the name to the Roll upon payment of all subscriptions then due and upon cause being shown to the satisfaction of the Council why such subscriptions were not previously paid.

40. Nothing herein contained shall prejudice the right of the Institution to the legal recovering of all arrears of subscriptions up to the date of striking the name off the Rolls.

41. In case the Council should be of opinion that any Member, who has been long distinguished in his professional career, from ill health, advanced age, or other sufficient causes, should not be called upon to continue his annual subscription, they may remit it. Also they may remit any arrears which are due from an individual, or may accept a collection of books, or drawings or models, or such other contribution as, in their opinion, under the circumstances of the case, may entitle the person to be enrolled as a Life Subscriber, or to enable him to resume his former rank in the Institution which may have been in abeyance from any particular causes. These cases must be considered and reported upon by a Sub-Committee named for the purpose.

42. In case the expulsion of any individual shall be judged expedient by ten or more Members, and they think fit to draw up and sign a proposal requiring such expulsion, the same being delivered to the Secretary shall be by him laid before the Council for consideration. If the Council, after due inquiry, do not find reason to concur in the proposal, no entry thereof shall be made in any Minutes, nor shall any public discussion thereon be

permitted; but if the Council do find good reason for the proposed expulsion they shall direct the Secretary to address a letter to the person proposed to be expelled, advising him to withdraw from the Institution. If that advice be followed, no entry on the Minutes, nor any public discussion on the subject shall be permitted; but if that advice be not followed, nor a satisfactory explanation given, the Council shall call a Special General Meeting of Members and Associates, for the purpose of deciding on the question of expulsion; and if two-thirds of the persons present at such Special General Meeting, provided the number so present be not less than thirty, vote that such individual be expelled, the Chairman of that Meeting shall declare such expulsion accordingly, and the Secretary shall communicate the same to the individual.

MEETINGS.

43. Meetings for the Reading of Papers shall be held as frequently, and at such times, as the Council may determine.

TRANSACTIONS.

44. The *Transactions* of the Institution, including the Papers read at the Ordinary Meetings, and Reports of the Discussions by which they are followed, shall be edited by the Secretary, and printed under the direction of the Council.

45. A copy of each Volume of *Transactions* shall be sent free to every Member and Associate.

46. The Secretary, under the direction of the Council, may dispose of the surplus stock of *Transactions* which have been published more than three years, at a price of not less than One Guinea a Volume, provided a sufficient number remain on hand to supply the probable demand of new Members and Associates to complete their sets by the purchase of the back Volumes.

CHANGE OF ADDRESS.

47. Members and Associates are particularly requested to communicate to the Secretary any change of address.

INTRODUCTORY PROCEEDINGS.

The Meetings of this, the Nineteenth Session of the Institution of Naval Architects, were held on the 11th, 12th, and 13th April, 1878, in the Hall of the Society of Arts, John Street, Adelphi.

The opening Meeting was presided over by the Right Hon. Lord Hampton, G.C.B., D.C.L., President of the Institution, who commenced the proceedings by calling upon the Secretary, Mr. A. Sedgwick Woolley, to read the Report of the Council, which was as follows:—

REPORT OF COUNCIL, 11th April, 1878.

"The Council of the Institution are glad to be able to report to the Members and Associates that the finances of the Institution are in a satisfactory condition.

"The Accounts now presented to you show that the balance to the credit of the Institution on the 31st of December was £575 0*s.* 5½*d.*

"The outstanding Accounts since received for work done during the year 1877 amount to £630 7*s.* 3*d.* which will be included as usual in this year's Account. It must, however, be borne in mind that last year was an exceptionally heavy one, in consequence of the extra Session which was held at Glasgow necessitating the printing of a Volume of *Transactions* double the ordinary size, the price of which is included in the outstanding debts, of which indeed it represents no inconsiderable item.

"The Autumn Meeting at Glasgow was a great success, thanks, in a great measure, to the kindly and hospitable welcome accorded to the Institution by the Institution of Engineers and Shipbuilders in Scotland at Glasgow.

"The Council have been obliged to move the Offices of the Institution, and in doing so have taken into their serious consideration the fact that at the foundation of the Institution the establishment of a Professional Library was contemplated as an efficient means of promoting one of the objects of the Institution, and Members and Associates were requested to contribute towards its foundation. In furtherance of this object Volumes of *Transactions* have been exchanged with other learned Societies, and many valuable books have been from time to time presented to the Institution, and a valuable Professional Library has now been collected.

"Some suitable Rooms were then greatly needed, for the purpose of containing this Library, where Members and Associates might consult and study such works as they wished and such Offices have now been found at No. 5, Adelphi Terrace, London, where the Institution has secured handsome Rooms, overlooking the Thames Embankment, and eminently suited to the purpose.

"The central position of these Rooms will, it is hoped, be of special advantage to those Members and Associates who reside out of London, and who may be glad of some such place of meeting and reference.

"The rent of these Rooms, however, is double that given previously, and to furnish them in a proper manner, and maintain a good Professional Library, would cost more than the Funds of the Institution could support.

"The Council have come to the conclusion, therefore, that it is desirable to found a Library Fund, and appeal to the Members and Associates who desire to contribute towards it to do so.

"A List has been opened and many gentlemen have already subscribed to start the Fund.

"It is proposed with the amount collected to furnish the new Offices in a suitable manner, and to devote the surplus money accruing therefrom in future towards defraying the additional expense of rent, and adding to and maintaining the Library under the direction of a Library Committee.

"The Council last year offered a Gold Medal for the best Paper read at the Meetings, but they are of opinion that though many of the Papers are on important subjects, possess considerable merit, and form a valuable addition to the *Transactions* of the Institution, they are unable on this occasion to select any one

Paper possessing in a sufficiently high degree those qualities of original thought and investigation which were contemplated by them as justifying the award of the Gold Medal.

"They have therefore decided not to award the Gold Medal for any Paper read last year, and have come to the conclusion that in future the Gold Medal of the Institution should not be announced for Annual Competition, but that it should be reserved as a mark of high appreciation for any Paper of exceptional merit that the Council may think specially deserving such notice.

"The Council have to deplore the loss by death of one of their number, Mr. Alexander Moore, Chief-Constructor of Devonport Dockyard, of Mr. B. Sorensen, Member, and Admiral W. C. Chamberlain and Mr. G. Lockwood, Associates."

Institution of Naval Architects.

Statement of Income and Expenditure for the Year 1877.

Dr.							Cr.					
1876.		£	s.	d.	£	s.	d.	1877.	£	s.	d.	£	s.	d.
Dec. 30th.	To Balance:—							Dec. 31st.	By Cash paid:—					
	In Treasurer's hands	369	9	2					Rent of Rooms	100	0	0		
	In Secretary's hands ...	87	18	6					Cleaning ditto	13	0	0		
					457	7	8						113	0	0
1877.									Attendance at London Meetings	16	9	6		
Dec. 31st.	To Cash received:—								Reportings at ditto	45	0	0		
	Annual Subscriptions				1,026	11	9		Abstract of Proceedings ...	11	12	6		
	Volumes sold				98	1	0		Advertising	46	1	6		
	Gold Medal for Marine Boilers, and Die from Mr. Carlyle as per contra				27	11	0						119	3	6
	Admiralty Grant				250	0	0		Attendance at Glasgow Meetings	10	10	0		
	Canoe Club				20	0	0		Reporting at ditto	32	14	3		
									Abstract of Proceedings ...	13	1	6		
									Travelling Expenses	23	9	4		
													79	15	1
									Printing Vol. XVII., Miscellaneous	291	15	6		
									Binding Vol. XVII.	33	1	0		
									Engraving, Vol. XVII.	78	12	6		
									Distribution of Vol. XVII. ...	21	7	4½		
													424	16	4½
									Stationery, 1876				12	2	0
									Fire Insurance				1	0	0
									Gold Medal and Die presented by Mr. Carlyle				27	11	0
									I. N. A. Gold Medal				12	11	6
									Banker's Charges				0	5	5
									Petty Disbursements ...				76	3	6
									Furniture and Repairs				8	2	0
									Library Expenses				24	19	10
									Salary of Secretary	250	0	0		
									Ditto of Assistant Secretary	55	0	0		
									Ditto of Occasional Clerk ...	74	4	8		
									Ditto of Messenger ...	25	11	6		
													404	16	2
								By Balance:—							
									In Treasurer's hands	546	8	11		
									In Secretary's hands—Current Expenses	28	16	1½		
													575	5	0½
					£1,879	11	5						£1,879	11	5

A. SEDGWICK WOOLLEY, *Secretary.*
J. D'A. SAMUDA, *Treasurer.*

We have examined the above written entries with the books and vouchers, and find them correct.

ROBERT CARLYLE, }
JAMES MACKENZIE, } *Auditors.*

21*st March*, 1878.

The following List of Donations to the Library was then read by the Secretary:—

"Proceedings of the Royal Society of London," Vol. XXVI. *Presented by the Royal Society.*

"Minutes of the Proceedings of the Institution of Civil Engineers," Vols. XLVII., XLVIII., XLIX., and L. *Presented by the Institution of Civil Engineers.*

"Proceedings of the Institution of Mechanical Engineers," for 1877. *Presented by the Institution of Mechanical Engineers.*

"Journal of the Iron and Steel Institute," for 1877. *Presented by the Iron and Steel Institute.*

"Journal of the Royal United Service Institution," for 1877. *Presented by the Royal United Service Institution.*

"Journal of the Society of Arts," for 1877. *Presented by the Society of Arts.*

"Transactions of the Institution of Engineers and Shipbuilders in Scotland," Vol. XX. *Presented by the Institution of Engineers and Shipbuilders in Scotland.*

"Transactions of the Society of Engineers," for 1865-77. *Presented by the Society of Engineers.*

"Annual Report of the Board of Regents of the Smithsonian Institution," for 1875-6. *Presented by the Board of Regents.*

"Lloyd's Register of British and Foreign Shipping," for 1877-8. *Presented by the Committee of Lloyd's Register.*

"Lloyd's Register of Yachts," for 1878. *Presented by the Committee of Lloyd's Register.*

"Underwriters' List of Iron Vessels," for 1877-8. *Presented by the Underwriters' Registry of Iron Vessels, Liverpool.*

"The Engineer," for 1877. *Presented by the Proprietors.*

"Engineering," for 1877. *Presented by the Proprietors.*

"Iron," for 1877. *Presented by the Proprietors.*

"Revue Maritime," for 1877. *Presented by the French Ministry of Marine.*

"Annales du Génie Civil," for 1877. *Presented by M. Eugène Lacroix, Paris.*

"Rivista Marittima," for 1877. *Presented by the Italian Ministry of Marine.*

"Proceedings of the Royal Society of Victoria," Vol. XII. *Presented by the Royal Society of Victoria.*

"Manual of Naval Architecture." By W. H. White, 1877. *Presented by the Author.*

"Des Lames de Haute Mer." By M. C. Antoine. *Presented by the Author.*

"Victoria Patents and Patentees," for 1876. *Presented by the Registrar-General of Victoria.*

"Vocabolario Nautico. *Presented by the Author.*

"Catalogue of the Special Loan Collection of Scientific Apparatus Exhibited at the South Kensington "Museum, 1876." *Presented by the Science and Art Department.*

"Abstract of Statement of the Extent of Character of the Work of the United States Board appointed to "test Iron, Steel, and other Metals. By R. H. Thurston. *Presented by the Author.*

"On a New Method of planning Researches, and of presenting to the Eye Results of Combination of "Three or more Elements in varying Proportions. By R. H. Thurston." *Presented by the Author.*"

"Salisbury Iron, its Composition, Qualities and Uses." By R. H. Thurston. *Presented by the Author.*

"Contributions to the Centennial Exhibition." By John Ericsson, LL.D. *Presented by the Author.*

The following Gentlemen (being duly recommended by the Council) were unanimously elected Members of the Institution:—Mr. Robert Davies Barrett, Naval Architect to Messrs. T. & J. Harrison of Liverpool; Mr. Richard Jago Butler, Draughtsman in the Department of the Controller of the Navy; Mr. James Cotsell, Draughtsman in the Department of the Controller of the Navy; Mr. George Eldridge, Manager of the Baltic Iron Works, St. Petersburg; Mr. Timothy Harrington, Consulting Marine Engineer, London; Mr. Frederick Jago, Shipwright Surveyor to the Board of Trade; Mr. Charles Langtry, Designer to Messrs. Laird Bros., Birkenhead; Mr. William George Littlejohn, Inspecting Engineer of Marine Engines and Boilers for H.M. Service; Mr. Henry Milnes Rait, Partner in the Firm of Rait & Lindsay, Glasgow; Mr. Charles Sells, Chief of the Designing Department of Messrs. Maudslay, Son & Field, London; Mr. Thomas Shilston, Surveyor to Lloyd's Register of British and Foreign Shipping; Mr. Bindon Blood Stoney, Engineer of Dublin Port and Docks Board; Mr. Robert Thompson, Senior Partner in the Firm of Joseph L. Thompson & Sons, Sunderland; Mr. James Garland Trevithick,

Partner in the Firm of Hodges & Trevithiek, Yacht Builders, Gosport; Mr. William Watson, Managing Constructor to the Firm of P. Hardcastle & Co., Sunderland; Mr. Thomas Williamson, Proprietor of the Firm of R. Williamson & Son, Shipbuilders, Harrington, Cumberland; Mr. Henry Wimshurst, Proprietor of the Ratcliffe Dry Dock, London.

The Secretary next read the list of Officers of the Institution, who were unanimously re-elected.

The PRESIDENT (Lord Hampton) then proceeded to deliver the following Opening Address:—

Gentlemen, we meet upon this occasion at the close of a year of which I think I am justified in speaking as the most eventful, and I am not sure that I may not add, the most satisfactory year which has passed ever since the establishment of this Institution. One of the circumstances, and by no means the only one, which enables me to speak, or requires me, I may say, to speak in these terms is the fact that for the first time in the history of the Institution we have carried out the intention, announced at our Meeting last year, of holding an Autumn Meeting. It was announced last year in this room to the Members assembled that we had accepted an invitation to hold an Autumn Meeting in the month of August last in the great City and Port of Glasgow. I, Gentlemen, felt it my duty as your President to attend that Meeting at Glasgow, and I have the greatest pleasure in saying, what I am sure must be confirmed by every one who hears me who was at that Meeting, that it was in every respect most successful. I think both the Members of the Glasgow Institution of Engineers and Shipbuilders and the Members of our Institution will agree that the object of the mutual interchange of experience and opinion which we of course contemplated, and which is one of the great advantages of such a Meeting, was fully answered. We received on the part of the shipbuilding interest of Glasgow the greatest possible attention. Their building yards were thrown open to us; we had the pleasure of seeing that magnificent establishment—I think I may speak of it as the most magnificent shipbuilding establishment in this country, and probably in the world—of Messrs. Elder in Glasgow, and also of Messrs. Denny, lower down the river. They invited us to see their yards, and in fact I think I may say the time we passed at Glasgow, while part of it no doubt was occupied most agreeably in receiving the hospitality so kindly shown to us, was devoted to the main objects of this Institution, and carried out in a manner that I think must have been most gratifying to every Member of both Institutions. But, Gentlemen, I cannot pass from my notice of that Meeting at Glasgow without expressing my high sense, and I am sure every Member of this Institution who hears me will share the feeling to which I am giving expression, of the cordiality and kindness which marked our reception in that City. I for myself shall never reflect on the Glasgow Meeting without feelings of the greatest pleasure, friendship and kindness towards those to whom we were indebted for so hospitable a reception, and I am sure that is the general feeling of all of our Members who went down there on that occasion.

Gentlemen, the reference which I have just made to the success of this first experiment of an Autumn Meeting naturally leads to the question whether or not in the future the Members of the Institution may think it desirable that this Autumn Meeting should be repeated, and should become a regular part of what I may call our system; and, Gentlemen, I ought to mention that the Council have received a very hospitable and kind letter of invitation from the great Port of Newcastle, expressing a hope that this Institution will hold an Autumn Meeting at that place this year. This question has been considered by the Council at their Meeting this morning, and the general opinion—I think I may say the unanimous opinion—of the Council has been that, while we are very sensible of the kind wish of the people of Newcastle to receive us there, and while, I think I may add, we hope in some future year we may have the pleasure of holding a Meeting at Newcastle, it is not desirable, at present at all events, for it to be considered that we have decided on the Autumn Meeting being a regular annual part of our proceedings; and it has been thought better, for the present year, that we should decline the invitation we have received from Newcastle, hoping, as I have already said, that in some future year we may be able to accept it. The Council have felt that it is desirable that we should look forward from time to time to hold Autumn Meetings, but not, for various reasons, as a settled annual custom, and amongst others for the reason that we have found this year that the expense of the Autumn Meeting is very considerable, and has formed an important charge on our finances.

Gentlemen, I will now pass to another respect in which I may speak of the past year as an eventful and satisfactory year—I allude to the great increase in our numbers, the number of Members and

Associates. The number of Members enrolled last year was eighty-eight, and Associates thirty-two, in all adding one hundred and twenty to our numbers, and I think I am justified in saying at this time that all—I think I may say all—the principal private shipbuilders in the kingdom have become Members and supporters of this Institution. The Institution has thus become more than ever that which all its friends and supporters would wish it to be, a national representative of the profession of shipbuilding, and a national gathering of those who are desirous in every way of promoting a science so essential to the welfare and prosperity of this great maritime country. Simultaneously, Gentlemen—and very naturally you will say simultaneously—with this increase in our numbers, we have found it desirable to provide increased accommodation for our Members, and we have by the assistance of a Committee entirely changed our residence, if I may so call it, and have now taken new premises on the Adelphi Terrace. They are extremely convenient, not only well adapted for the purposes for which we assemble here, but they will enable us to have the comfort, and more than comfort, the advantage of a library which we hope to establish in our Institution to which our Members who come from a distance may have the benefit of resorting, both for their personal convenience and for the purpose of obtaining any information which they may desire to receive.

I turn now to the Papers which are to be read to you during this Meeting, and here again I may say that they are of a more than usually interesting character, and their great interest arises from the circumstance which must be strong in the mind of every one who gives attention to the important subjects with which we have to deal—namely, the rapid increase of late years in the use of steel for those purposes which we have in view. Perhaps the strongest proof, or rather the two strong proofs of the rapid increase in the use of steel for shipbuilding are these. The one that, for the first time I believe at the close of last year, steel is now recognised at Lloyd's. I see Mr. Martell here, who I am sure will agree with what I say, that steel has not hitherto been recognised by Lloyd's, but that now for the first time it is so, and it is now extensively used in shipbuilding. As a proof of it I may refer to that great shipbuilding establishment in Glasgow—Messrs. Elder's building yard—and there we who went to Glasgow saw no less than six corvettes in course of building which were to be built of steel. You will have Papers on this subject. The first Paper, which Mr. Martell will be good enough to read, is on this subject of steel, and I believe we shall have a Paper by Mr. Parker showing the extent to which steel is now being used for boilers as well as for shipbuilding. I do not know whether I may venture to speak in very decided terms at present, but I think I may at all events say that the question of whether or not steel may be used for the armour plates of our men-of-war is also another question now under consideration and experiment—with what result I do not know whether I should be justified at present in stating—another proof, at all events, of the extent to which steel is likely to be made available for the purposes which we assemble here to promote.

There is another question, Gentlemen, of immense interest and importance, and one which I think has taken a very strong hold of the public mind in many points of view. I mean the use of torpedoes in war. I think, perhaps, it will be hardly prudent on my part, unprofessional as I am, and not connected with either of the great Services, to endeavour to express any decided opinion on the subject of torpedoes. In fact, I do not think that the trial of torpedoes in war, although no doubt they have been resorted to during the late war between Russia and Turkey, has as yet been carried to such an extent as to justify any very decided opinion being pronounced; but there can be no doubt that the present impression on the public mind is that they are a very formidable and dreadful engine of war, and I confess myself I think them so horrible an engine of war, and likely whenever used, if successfully used, to produce results so dreadfully painful and disastrous that nothing would please me more than to hear that torpedoes had been abandoned altogether as perfectly impracticable. But, Gentlemen, I am afraid that we have not come to that, although I for one should be very glad to hear it.

I cannot help adverting to some very important additions to our naval strength—perhaps they do not come quite strictly within our subject of naval architecture, but, looking at all the circumstances, I am sure that every one must feel gratified to know that quite lately Her Majesty's Government have made some important additions to the power of the Navy of this country by the purchase of vessels constructed in our yards here in England for foreign powers. There is a very splendid ship, originally called the *Independencia*, which was built for the Brazilian Government; and, I think, three ships, which were originally built for the Turkish Government, but which the Turkish Government found it, under the circumstances, convenient to part with, and Her Majesty's Government wisely, as I venture to think,

purchased these important additions to the strength of our Navy: thus holding out an additional proof of the value of the splendid private building establishments of this country, in being thus able to construct vessels which, under favourable circumstances, may be made use of to add to its naval strength.

Gentlemen, there is another point which I think I must touch upon, although I will not say much about it. It is hardly ripe for any formal announcement, but you will not be surprised, after the lapse of nearly twenty years—I think this is the nineteenth occasion upon which I have had the honour of presiding over you in this room—if we have found, as most Institutions under similar circumstances have found, that it may be desirable in some respects to revise our Rules. The attention of the Council has been given to this subject, especially with the object of revising the mode of election of the Council of the Institution. A Report on this subject has been prepared, but it has not yet been formally adopted, and I think, therefore, it would be premature for me at present to dwell upon it. I may mention that it is our intention to revise the Rules under which the Council of this Institution is annually appointed, and whenever we next assemble for a General Meeting I hope that those new Rules will be submitted to you, and approved by the Members of the Institution.

Gentlemen, there is one other subject which I cannot pass by in silence, and yet to which it is very painful to allude—I mean the dreadful event which has shocked this country, and which has shocked us all—the loss of the *Eurydice* off the Isle of Wight. I think upon an occasion such as this it would be almost a breach of the feelings which we must all entertain if I were not to make some reference to that dreadful event, not with a view of criticism, not with a view of attaching blame—even if blame were due, no one would desire to do that—but I think it must be in accordance with your feelings, as it is, I confess, in accordance with my own, that, assembling here as we do in immediate connection with the maritime interests of the country, we should express our regret at this most deplorable disaster. I think I should be wanting on this occasion if I were not, in your name, and for you as a great Institution connected with our naval interests, to express our deep regret and our hearty sympathy for those who lost their friends by that unfortunate and dreadful accident. I cannot refrain from saying, that which I am sure you must all feel, that we regard it with the deepest pain and the most sincere sympathy.

Gentlemen, I am not aware that I need detain you any longer; but, in conclusion, I would ask you to submit to the same practice that we have always followed of limiting our Papers to twenty minutes and the speeches in discussing those Papers to ten minutes; and in carrying out those Rules, as your President, I shall trust to the kind support on your part which I have always experienced when occupying this Chair. Gentlemen, I will only express my earnest hope that the business which we are now about to commence may afford additional proof of the great value and the high reputation of this admirable Institution.

Since the issue of Vol. XVIII. the following Gentlemen have been added to the lists of Members and Associates respectively:—Messrs. Robert Davies Barrett, Richard Jago Butler, James Cotsell, George Eldridge, Frederick Jago, Charles Langtry, Henry Milnes Rait, Charles Sells, Thomas Shilston, Bindon Blood Stoney, Robert Thompson, James Garland Trevithick, William Watson, Thomas Williamson, and Henry Wimshurst, Members; and Messrs. Francis Louis Adcock, Engineer to the Cape Copper Mines, South Africa; John Howard Biles, Draughtsman in the Department of the Director of Naval Construction, Admiralty; James Bone, Partner in the Firm of Foulds & Bone, Greenock; Francis Joseph Cresswell, Member of the Royal Thames Yacht Club; Solomon Israel Da Costa, Underwriter, Lloyd's; Captain Cavelier de Cuverville, Naval Attaché to the French Embassy, London; Messrs. Leopold Eidlitz, junior; George Friedrich Heyl, Inventor of Patent Anti-fouling Composition for Ships' Bottoms; Captain Thomas Hodgson, Overlooker and Inspecting Engineer for Messrs. Appleby and Co., West Hartlepool; Michael Henry Isaacs, Manufacturer of Anti-fouling Composition for Iron Ships' Bottoms; John Evelyn Liardet; Fritz F. Maier, Manager to the Imperial and Royal Station for the Improvement of Iron and Steel Industries, Stadt Steyr, Austria; Captain Augustus Henry Macdonald Moreton, Coldstream Guards; Commander Gerald H. A. Noel, R.N.; Messrs. Fritz Petke,

Engineer Superintendent of the Austrian Lloyd's, Trieste; George Pratt; Mark Heaton Robinson; Thomas Small, Marine Superintendent for Messrs. Donald Curric & Co.; Captain Charles Testa, Royal Portuguese Navy, Professor in the Royal Naval School, Lisbon; Edmond Thompson, Shipbroker and Shipowner; Andrew Thomson, Yachting Editor of *Land and Water;* Robert Hardy Williamson, Assistant in the Firm of R. Williamson & Son, Shipbuilders, Harrington, Cumberland; and George Edward Wood, Associates.

During the same period the Institution has sustained the loss of the following Members and Associates by death :—Admiral the Right Hon. the Earl of Lauderdale, K.C.B., Vice-President; Admiral the Hon. Sir Frederick W. Grey, G.C.B., Vice-President; Admiral Sir Hastings Yelverton, K.C.B., Vice-President; John Penn, Esq., F.R.S., Vice-President; Alexander Moore, Esq., Member of Council; Hugh Morton, Esq., and B. Sorensen, Esq., Members; Admiral W. C. Chamberlain and G. Lockwood, Esq., Associates.

PAPERS AND DISCUSSIONS.

ON STEEL FOR SHIPBUILDING.

By B. MARTELL, Esq., Chief Surveyor of Lloyd's Register of British and Foreign Shipping, Member of Council.

[Read at the Nineteenth Session of the Institution of Naval Architects, 11th April, 1878; the Right Hon. LORD HAMPTON, G.C.B., D.C.L., President, in the Chair.]

THE question of the use of steel for shipbuilding purposes has occupied considerable attention for many years by those interested in shipping, and one or more valuable Papers, bearing on this subject, have been read at the Meetings of this Institution; but it is, perhaps, not too much to say that circumstances have now brought the question to the front in a more urgent and practical form than heretofore, and, in my opinion, it was never so ripe for discussion as at the present time; and just now the production of any experience which can throw light on its mechanical or commercial aspect will be of special value and significance.

The prominent position occupied by mild steel during the last year or two, and particularly very recently, has induced shipowners as a body to look forward with the greatest interest to the probabilities of its becoming the material for shipbuilding in the immediate future, and they desire at the present moment to be informed of the advantages or otherwise which experience so far has already shown to arise from the use of this material for the construction of vessels for general mercantile purposes.

It has been long felt that the production of a material like the present mild steel, possessing its properties of ductility and superior strength, and being perfectly uniform and homogeneous in quality, would be a most desirable substitute for the ordinary iron used in the construction of our mercantile vessels. Till the last year or two much doubt existed whether these conditions could be ensured to the required extent, and especially whether it could be produced at such a cost compared with iron as would enable shipowners to recoup themselves for the additional outlay.

The time has now come when it is said by many others besides the manufacturers, that steel can be used with as much confidence as iron; and it is held that whilst the properties of mild steel are in every respect superior to iron, the cost—having regard to the reduced weight required—will warrant the shipowner, from a commercial point of view, in adopting the lighter and stronger material.

These opinions are undoubtedly shared by many shipowners, as would appear from the fact of steel vessels at the present time being in course of construction. I may mention that during the last twelve months the Committee of Lloyd's Register of Shipping have had placed before them for their approval the particulars of over 5,000 tons of sailing ships, and 18,000 tons of steamers, with a view, if built, to a class in the Register Book of their Society.

These facts all seem to indicate that steel shipbuilding on a large scale is becoming a reality, and this is why I think the present an opportune moment to raise the

question before the Members of this Institution, as a discussion of it here cannot fail to afford valuable information to all who are interested in the subject.

The question appears to present itself for consideration under the two following heads :—

Firstly. The peculiar properties of mild steel for shipbuilding, as regards its comparative strength, uniformity, and rigidity; the changes observable under manipulation, the effects of riveting, and the general durability as compared with iron.

Secondly. The relative cost, and commercial advantages or otherwise to be derived from its use in the construction of sailing ships and steamers for various purposes of trade.

Until recently the experience of those who had used and observed the working of steel for shipbuilding was not so satisfactory as to justify them in recommending its general adoption for the construction of vessels of all sizes and for every purpose of trade. On the other hand, it is only fair to admit that steel has been used, and used successfully for shipbuilding, off and on for many years, but I believe the success has been achieved only where the material has been very carefully selected, and due precautions have been taken in its use.

A large number of small vessels have, for instance, been built for special purposes of trade, and have done their work well; and even merchant ships, above 1,000 tons register, have been so constructed, and fully answered the expectations of their owners. One sailing ship of 1,200 register tons has been employed in general purposes of trade for the last fourteen years, and is so employed at present, and structurally has given every satisfaction.

These facts show that we are not altogether wanting in experience of steel for shipbuilding, even in ordinary sea-going ships. At the same time, it is only too true that in other attempts at steel shipbuilding very brittle plates have been found to be interspersed amongst others possessing every desirable quality, and this gave rise, and justly so, to the distrust which for a long time has been felt in using steel in an ordinary manner for general purposes of ship construction.

Experience has now, however, abundantly proved that mild steel can be manufactured either by the Bessemer or Siemens process, possessing qualities of ductility in connection with tensile strength and general uniformity, which render it much superior to the iron in ordinary use, and fully meriting the high praise which has been claimed for it by the manufacturers; and, what is of not less importance, this material can be produced at a comparatively cheap cost, thus rendering its adoption practicable.

After most careful inquiries I have elicited but one opinion from those who have recently used it in shipbuilding, and those whose duty it has been to officially inspect the working of it, to which I can bear my personal testimony, that within certain limits of thickness it is a material which can be used with the greatest confidence under precisely the same conditions as would be required in the use of iron.

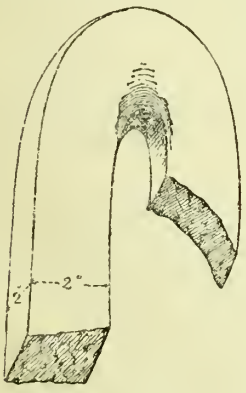
With a view, however, to have further information on the properties of this mild steel under the various conditions to which it would be subjected in the ordinary course of constructing merchant ships, the Committee of Lloyd's Register have recently at considerable expense caused many series of experiments and tests to be made under the inspection of their officers, and I have much pleasure in laying the results of these before the Meeting, together with some others furnished me of a trustworthy

character. And I should say we feel much indebted to some of the principal steel manufacturers of Bolton, Sheffield, Scotland, and on the Continent, for the assistance they have afforded us and the expense they have incurred in facilitating these inquiries.

These tests, it will be seen, embrace the qualities of the material as regards its tensile strength, elongation, effects of punching and drilling on steel plates, annealed and unannealed, as compared with iron; also the strength of riveted joints of steel plates as compared with iron, &c.

Information on some of these points already existed, but the tests were generally confined to thin plates and small samples, as in the Tables of Results furnished by Mr. Riley in the Paper on Steel read before the Members of this Institution in 1876, and in some of our own earlier tests. In the examples now given the tests have been extended to thicker and larger specimens of plates, whilst the tests on riveted joints and on punching are of more value from the fact of a comparison being made between steel and iron under the same conditions, which is of practical importance in dealing with this branch of the subject.

While this mild steel, as before said, is found to be sufficiently ductile for every purpose for which it may be required, and its uniformity of quality is admitted to be remarkably great, it is at the same time, with proper care, capable of being *welded* with as much ease, and as satisfactorily as iron. This has been shown to the entire satisfaction of many of our surveyors, and quite recently in the case of one of them who has been conducting a series of experiments on steel at one of the principal steel manufactories on the Continent. It is also confirmed, as will be seen by the specimen produced, which has been forwarded to me by Mr. Kirk, of Glasgow. This specimen was "shingled" from the cuttings of steel plates in ordinary use, in the same way and at the same heat as would be done with common scrap iron. It was bent, as you see it, cold, till the ends closed, and finally broke. A piece of the same material was tested and found to stand a tensile strain of 26 tons to the square inch. Mr. Kirk observes, "In all this it behaves just as ordinary iron. It welds as freely, and does not lose its strength by the process. In fact, it is cleaner and more perfect in the welds than iron." This is very important, as considerable doubt still exists in many minds whether it can be safely used for forgings.



The question of the *qualities* of the material, however, is only one part of the subject in ship construction; another, of equal importance, is the *connection* of the several parts. And this leads to the consideration of the most fitting material for the rivets of steel ships, and the sizes and arrangements of the riveting. Although I believe the Admiralty have not yet adopted steel rivets in ships built of steel for the Royal Navy, yet steel rivets have been used very satisfactorily in two steel vessels recently built by Messrs. Laird Brothers of Birkenhead. They have also been adopted by Messrs. J. and G. Thomson on the Clyde, in a large steel vessel building by them, with perfect success. In fact, the latter gentlemen state they find less liability to injury from overheating in steel than in iron; but the rivet steel for this purpose was in both cases of a specially mild quality.

Experience has, however, shown that risks are incurred unless special means are adopted to ensure the rivet steel being of very mild quality, or that the rivets are uniformly heated, and at not too high a temperature.

To illustrate this, I may mention that the builders of a steel vessel, recently constructed, determined at first to adopt steel rivets. After one or two landing edges of the outside plating had been riveted, it was found by them that many of these rivets were broken off in the process, generally between the surfaces of the two plates they connected. In consequence of this the use of steel rivets was abandoned, and iron rivets of the best quality substituted throughout the plating of the vessel.

If we could ensure the efficiency of the steel rivets, their greater strength—which is shown to be one-fourth more to resist shearing than iron rivets of the same size and spacing—would enable us to obtain better joints, even with smaller rivets, if they were properly spaced; yet, if constant vigilance were required, where boys are employed to heat them in ordinary open furnaces, I should hesitate to advocate their general adoption. At the same time, when such satisfactory results as those referred to have been obtained, there does not appear to be much doubt that with steel specially prepared for the purpose, the rivets properly made, and with ordinary care in their use, satisfactory riveting can be made with steel rivets. And when the additional strength which they impart is considered, it becomes a matter of much importance that their use should not be unduly restricted, unless more evidence than we appear to have at present shows that danger is likely to result therefrom.

There is no doubt the question of riveting is still open to much consideration, and ample room is left for a most useful series of experiments as to the best diameter and pitch of rivets in relation to the thickness of the plates; effects of single, double and treble riveting; also the comparative advantages of steel and iron rivets. I venture to express the hope that the Admiralty, steel manufacturers, and others, will be enabled to see their way to assist us in extending these tests in the direction indicated.

In Table I. are given the results of some tests of the strength of iron and steel plates connected together by butt straps and with iron and steel rivets. The first nine of these in the Table were kindly prepared for testing by Messrs. J. Elder & Co., and the following are the mean results:—

Firstly. Iron plates, connected together by iron butt straps of the same thickness, double chain riveted with iron rivets, and having the holes punched, show a mean tensile strength of 17·9 tons per square inch, and in all these cases, the plate broke through the rivet holes.

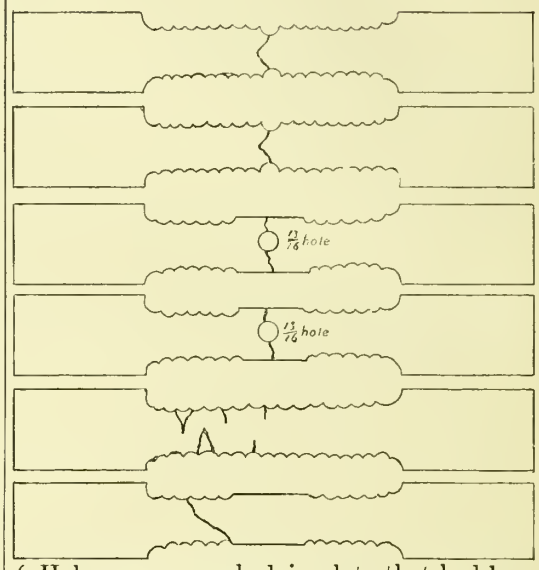
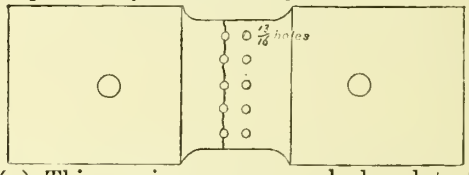
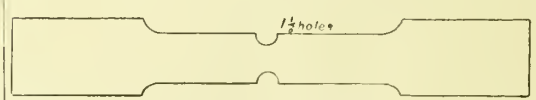
Secondly. Steel plates, not annealed after punching, connected together by a steel butt-strap of the same thickness, double-chain riveted with iron rivets, withstood a tensile strain of 16·7 tons per square inch of rivet area, the tension on the plate between the rivet holes being only 15·3 tons per square inch, when the rivets sheared.

Thirdly. In a similar experiment to the foregoing, with the exception of the rivets being arranged zig-zag instead of chain, the rivets were sheared at 19·2 tons per square inch, or a mean of 17·9 in the two experiments.

Fourthly. Steel plates, not annealed after punching, connected together by steel butt-straps of the same thickness, double chain riveted with *steel* rivets, show a mean tensile strength of 22·5 tons per square inch—the rivets shearing in some cases, and in others the plates breaking.

From these results it appears the full strength obtained from double riveting, with iron rivets, does not exceed a mean of about 18 tons per square inch. In view, therefore, of steel plates unannealed, as shown, withstanding a tensile strain of $22\frac{1}{2}$ tons at the rivet holes, double riveting with iron rivets is not sufficient to ensure the strength

TABLE II.—STEEL: SHOWING LOSS OF TENSILE STRENGTH DUE TO PUNCHING, &c.

No.	DIMENSIONS.	Plain Plates.	ULTIMATE TENSION.					REMARKS.
		Ultimate Tension.	Number and Diameter of Rivet Holes.	Punched and rimed.	Punched and annealed.	Punched and not annealed.		
		Tons per square inch.		Tons per square inch.	Tons per square inch.	Tons per square inch.	Loss from plain plate per cent.	
1	in. in. $\frac{1}{4}$ plates, $5\frac{1}{2}$ broad ...	32·07	in. Two $\frac{5}{8}$	.....	.....	29·48	8·1	Punched with open die.
2	$\frac{1}{4}$ plates, $5\frac{1}{2}$ broad ...	.....	Two $\frac{5}{8}$	.....	29·1	29·0	.....	
3	$\frac{9}{32}$ plates, $4\frac{3}{4}$ broad ...	28·06	Two $\frac{3}{4}$	.....	26·15	23·79	15·2	A drilled specimen stood 24·83 tons per sq. in.
4	$\frac{5}{16}$ plates, $4\frac{3}{4}$ broad ...	29·85	Two $\frac{3}{4}$	.....	29·27	27·59	7·5	
5	$\frac{3}{8}$ plates, $1\frac{5}{8}$ broad ...	30·0	One $\frac{9}{16}$	.....	26·5	26·8	10·6	
6	$\frac{3}{8}$ plates, $2\frac{11}{16}$ broad ...	28·43	One $\frac{5}{8}$	.....	.....	23·20	18·4	
7	$\frac{3}{8}$ plates, $6\frac{3}{4}$ broad ...	.....	Two $\frac{3}{4}$	.....	27·73	25·21	.....	
8	$\frac{3}{8}$ plates, $6\frac{3}{4}$ broad ...	29·59	Two $\frac{13}{16}$	.....	.....	24·06	18·7	
9	$\frac{3}{8}$ plates, $2\frac{1}{8}$ broad ...	31·48	*see* sketch	.....	.....	31·18	.....	
			do.	.....	.....	31·18	.....	
			do.	.....	.....	29·9	5·0	
			do.	.....	.....	30·55	3·0	
			do.	.....	.....	28·18	10·4	
			do.	.....	.....	27·91	11·3	
10	$\frac{7}{16}$ plates, 3 broad ...	27·61	One $\frac{7}{8}$	.....	.....	·2822	nil	Holes were punched in plate that had been previously tested to rupture.
11	$\frac{15}{32}$ plates, $7\frac{3}{4}$ broad ...	28·98	Two $\frac{7}{8}$	.....	.....	21·38	26 2	
12	$\frac{15}{32}$ plates, 16 broad ...	.....	*see* sketch	.....	28 4	25·1	.....	
13	$\frac{1}{2}$ plates, $7\frac{3}{4}$ broad ...	.....	Two $\frac{7}{8}$	.....	31·28	24·95	.....	
14	$\frac{1}{2}$ plates, $7\frac{3}{4}$ broad ...	28·9	Two $\frac{7}{8}$	.....	30·5	27·84 (A) 27·54	3 7 4·8	(A) This specimen was punched and tested as it came from the rolls being unannealed.
15	$\frac{19}{32}$ plates, $7\frac{3}{4}$ broad ...	29·55	Two $\frac{7}{8}$	.....	.....	19·57	33 8	
16	$\frac{5}{8}$ plates, $7\frac{3}{4}$ broad ...	.....	Two $\frac{7}{8}$	.....	27 92	23·28	.....	
17	$\frac{11}{16}$ plates, 4 broad ...	27·05	*see* sketch	28·81	28·98	22·92	15·2	
18	$\frac{11}{16}$ plates, $4\frac{1}{4}$ broad ...	27·0	One $\frac{7}{8}$	25·69	.....	24·46 21·04	9·4 22·1	Very open die.
19	$\frac{3}{4}$ plates, $8\frac{1}{4}$ broad ...	26·4	Two $\frac{7}{8}$	28·2	31·71	20·0 18·69	24·2 28·7	Punched with close die. Punched with open die.
20	$\frac{3}{4}$ plates, $8\frac{1}{4}$ broad ...	.....	Two $\frac{7}{8}$	21·72*	28·58	20·5 19·08	....	Punched with close die. Punched with open die.

* This specimen broke through pin-hole without signs of distress at the rivet holes.

of the plates being utilized; and that in order to accomplish this, either the rivets should be larger or more closely spaced, or the butts would have to be *treble* riveted with iron rivets, or double riveting with steel rivets adopted.

Other experiments have been made on *punching* plates, both annealed and unannealed, and also by having holes drilled, and by punching and subsequently enlarging the holes by riming.

The results of these tests, as shown in Tables II., III. and IV., are of great interest, as showing:—

Firstly. That steel plates very thin suffer less from punching than iron.

Secondly. That the difference in loss of strength by punching on steel and iron does not appear sufficiently great to require special precautions to be taken for steel more than for iron in plates up to $\frac{8}{16}$ths of an inch in thickness.

Thirdly. That in plates above $\frac{8}{16}$ths of an inch in thickness, the loss of strength of iron plates by punching ranged from 20 per cent. to 23 per cent., while in steel plates of the same thickness it ranged from 22 per cent. to 33 per cent. of the original strength of the plate between the rivet holes. An occasional plate both of iron and steel showed a smaller loss than the minimum here indicated, but they were exceptional cases so far as these experiments go.

Fourthly. That by annealing after punching the whole of the lost strength was restored, and in some instances greater relative strength was obtained than existed in the original plates.

Fifthly. That the steel was injured only a small distance around the punched holes, and that by riming with a larger drill than the punch, from $\frac{1}{16}$th to $\frac{1}{8}$th of an inch around the holes, the injured part was removed, and no loss of strength was then observable any more than if the hole had been drilled.

Sixthly. That in drilled plates no appreciable loss of tensile strength was observed.

From these conclusions the question arises, whether, in using steel plates for shipbuilding, above $\frac{8}{16}$ths of an inch in thickness, they should be annealed or the holes rimed after punching.

Here again we must fall back upon the comparison with iron. When we hear the complaint that steel loses so much by punching, it often escapes attention that iron also loses considerably by that operation, and that allowance must be made for this. If then we start with iron at a normal strength of 20 tons, and steel at 28 tons per square inch, and suppose the reduction in scantlings for steel is 20 per cent. from those of iron, it can easily be shown, that if the steel loses 30 per cent. by punching, and the iron 22 per cent., the balance of strength still remains slightly with the steel; and this agrees pretty much with the experiments made on the strength of riveted joints.

The loss due to punching is nevertheless a most important matter, and serious attention should be given to mitigating it. Punching with an open die has been strongly recommended as a means of reducing it, and experiments are not wanting to support this view.

On the other hand, however, the recent experiments referred to do not sufficiently bear it out. Improvements in the mode of punching have been suggested, and there is probably much to be hoped for from an advance in this direction. In the meantime there are other points which tell in favour of the steel ship. Practically, the holes in the outside strakes of plating have nearly all the distressed or injured parts around the hole removed by counter-sinking; and it would be easy to make this still more effective, so

that, under any circumstanees, there would remain in the skin of the vessel only the inner strakes of plating and the butt-straps to be dealt with.

When, however, it is considered that the probable cost of annealing all the outside plating, stringers and butt-straps, would not exceed a few shillings per ton of material in the ship, I cannot think it will form a serious impediment to the introduction of steel shipbuilding even if it be found indispensable. It would, I conceive, be better to make a somewhat greater reduction in the scantlings than to dispense with restoring the strength at the butts in large ships by annealing or riming the holes, or by some other such effectual means of achieving this object as may hereafter be devised. In the same way, it appears to me that in all ships where the sheerstrakes, garboard-strakes and deck stringer plates are above $\frac{8}{16}$ths of an inch in thickness, they should, together with the butt-straps, be annealed after punching, in order to utilize as far as possible the full strength of the material at these important parts.

A step in the direction of rendering annealing or riming after punching unnecessary has, I am glad to say, been taken by the introduction of the patent spiral punch, from which results of a very encouraging nature appear to have been obtained. On reference to Table IV. it will be seen that by the use of this punch the strength of the material after punching was about $2\frac{1}{2}$ tons per square inch greater than by the use of the ordinary punch, whilst greater ductility was found to exist around the holes.

Not a bad indication of the merits of a punch is the smallness of the power required to drive it through the plate; this measures the work that has to be absorbed in the production of heat or distortion during the operation of punching. I have been supplied with particulars which go to show that the spiral punch requires only about two-thirds the force behind it that an ordinary punch does; and, besides this, it acts more injuriously on the piece punched out, and less so on the surrounding plate. Further improvements still may, it is hoped, be made in this direction.

Another point of importance in considering the reduction of scantlings in steel ships is the comparative rigidity of steel and iron. The efficiency of a ship must in all cases depend in a great measure upon her general rigidity, as well as upon her longitudinal strength, and it is important in making reductions in the sizes of the frames and reserve frames that this feature should be maintained. Also in reducing the thickness of the plating, especially towards the ends of a ship, it is necessary to think of its rigidity between the frames, and of the means of imparting strength to resist panting and distortion.

I have given the results of a few experiments intended to throw some light on this point, and they do not, so far as they go, speak so favourably for the steel as the tensile and other experiments do. They consisted in testing the comparative stiffness of strips of steel and iron plate, and of some plates and angles combined, by supporting the specimens near the ends and weighting them in the middle, and measuring the amount of deflection at successive loads. The test pieces were supported, but not rigidly held by the ends, and so differed in a measure from the condition of the skin plating between the frames of a ship, and the steel might probably have compared somewhat better if the ends had been fixed. But the experiments which are shown in Tables V., VI., VII. and VIII. are, nevertheless, instructive as far as they go, and I hope we shall yet see more extensive and complete experiments in the same direction.

Another point of interest may be mentioned here. Some inconvenience having

been found to exist from fixing a definite length on which the elongation under tensile strain should be measured, owing to the length not suiting some of the private testing machines, some experiments were made to ascertain how the per-centage of extension varied with the length of the specimen, and in Table IX. the per-centages of extension in 2, 4, 6 and 8 inches are given, and may prove useful.

In treating of this subject of steel for shipbuilding, it is not, as I have before intimated, sufficient to show the superior qualities of steel as compared with iron for shipbuilding purposes; but it is also necessary, before it will be generally adopted, to show that it can be profitably employed.

The number of people who would leave the beaten track and have their vessels built of a comparatively untried material like steel, simply on the faith or in the hope that they would thereby possess stronger vessels, and perhaps be liable to less risks of loss from collision, grounding or other causes, would, I fear, be very small, unless it could be shown them either that they would not cost more than if built of iron, or that a fair profit might be looked for from the additional outlay. This is not due to any want of appreciation of a superior vessel, or disregard to the increased safety to property and lives resulting therefrom, but simply from the hesitation people naturally feel to embark in a new thing, and from the necessity, if they wish to compete successfully, in these difficult times, of regarding the question from a business point of view.

It will therefore perhaps not be without interest to make a brief comparison of the cost of building iron and steel vessels at the present prices, and to endeavour to point out the advantages, or otherwise of adopting the two descriptions of materials, allowing a reduction as admitted by the Committee of Lloyd's Register in the weight of steel as compared with iron.

A point having some bearing on this is that of the relative density of steel and iron; and in consequence of statements to the effect that there was a difference of as much as 4 per cent. between them, the steel being that much heavier than iron, I have endeavoured to obtain trustworthy data upon the point. Messrs. John Brown & Co., of Sheffield, have very kindly made some experiments on the subject with the following results:—

	Specific Gravity.	Pounds per Cubic Foot.
Boiler plate iron, average	7·618	476·125
Mild steel plates „	7·820	488·75

Difference 2·66 per cent. steel heavier than iron.

I have also obtained some data from Mr. Bessemer, which shows still less difference between the weight of steel and iron, and I am therefore constrained to believe that the difference of 4 per cent. alleged is considerably above the mark.

It is evident that vessels engaged in carrying dead weight must realize greater advantage from the use of lighter scantlings than the ship carrying measurement goods. I have therefore selected for the purpose of comparison three types of vessel, *viz.*:—

Firstly. A screw steamer suitable for the India trade.

Secondly. A sailing ship of about 1,700 register tons to be employed in general trade.

Thirdly. A screw steamer designed for dead-weight carrying in the ore trade.

The principal dimensions of the first of these vessels are:—Length, 316 feet; breadth, 36 feet; hold, 25 feet 6 inches. Gross register tons 2,300, and of 200 horse-power.

Such a ship built of iron at the present time to class 100A would cost complete for sea about £36,000, and would require about 1,090 tons nett of iron. The following may be taken as a statement of a Bombay voyage:—

Allowing 800 tons of coals for the ship's use, the cargo on which freight would be paid would be 2,200 tons, at 30*s.* per ton		£3,300
Homeward cargo, 3,500 tons measurement, goods at 40*s.* per ton		7,000
		£10,300
Expenses on voyage	£7,300	
Insurance on £36,000 for four months at 8 % per annum ...	960	
		8,260
		£2,040

Equivalent to a profit of, say, 5½ % on the voyage.

Now, if we suppose a similar ship built of steel, of the decreased scantlings, and to class 100A, to take about 890 tons nett of steel, she would cost about £40,500, and the statement of a similar voyage would stand thus:—

Allowing 800 tons for coals for ship's use, the cargo on which freight would be paid would be 2,400 tons, at 30*s.* per ton		£3,600
Homeward cargo, 3,500 tons measurement, goods at 40*s.* per ton		7,000
		£10,600
Expenses on voyage	£7,300	
Insurance on £40,500 for four months at 8 % per annum ...	1,080	
		8,380
		£2,220

Or a profit of about 5½ % on the voyage.

As, however, it may occur that a dead-weight cargo out and home could be secured, such as coals out and rice home, the comparison in such a case would be different, and would show, as follows, a considerable advantage in favour of the steel ship:—

IRON SHIP.

Cargo out (say coals) 2,200 tons at 20*s.*		£2,200
Rice home 2,700 tons at 60*s.*		8,100
		£10,300
Expenses on voyage	£7,300	
Insurance at 8 %	960	
		8,260
		£2,040

Or a profit on the voyage of, say, 5½ per cent.

STEEL SHIP.

Cargo out (say coals) 2,400 tons at 20*s.*			£2,400
Rice home, 2,900 tons at 60*s.*			8,700
			£11,100
Expenses on voyage	£7,300		
Insurance at 8 %	1,080		
			8,380
			£2,720

Or a profit on the voyage of, say, $6\frac{3}{4}$ % as against $5\frac{1}{2}$ % for the iron ship.

If, now, we take an iron sailing ship of 1,700 gross register tons, to class 100A, taking about 840 nett tons of iron, she would cost about £22,000. A similar vessel built of steel would require about 680 nett tons of steel, and would cost about £25,000.

The difference in the nett weight of material or carrying capacity would consequently be about 160 tons.

A comparison cannot so easily be made in this case as in the former, as the conditions are more varied; but there does not appear to be much doubt that with a steel ship, properly designed, and properly managed, she would, under ordinary circumstances, hold her own against the cheaper iron vessel, while with exceptional freights of full dead-weight cargoes out and home, the additional 160 tons capacity would cause a balance to appear in her favour. I am not alone in this opinion, as a sailing ship of about 1,700 tons is now being built of steel, and the experienced and intelligent owner of her fully expects, whilst having a stronger and better ship, to be enabled to thus recoup himself for the additional outlay. However, those who, like myself, desire to see the general use of this superior material as a substitute for iron, can only hope that this commercial element, which at present is somewhat nicely balanced, will eventually declare itself still more clearly in favour of steel, so as to lead to its wholesale adoption for general shipbuilding purposes.

There is no doubt that for vessels intended for special trades, where a light draught of water is essential, and where the cargo consists entirely of dead-weight, such as the ore and some other trades, the use of steel, even as the matter now stands, will be found most advantageous.

If we take a screw steamer suitable for the ore trade, to carry about 1,300 tons, and having a double bottom, she would cost complete for sea about £17,500. If built of steel, the cost complete would be about £19,000, and such a vessel would carry about 75 additional tons on the same draught of water.

As these vessels make a voyage a month, say at 15*s.* per ton, the gain per annum will be found to exceed 25 per cent. on the additional outlay, or 2 per cent. on the whole cost of the vessel.

Other illustrations might be given, but it is thought these are sufficiently typical to show that steel can be profitably used in building vessels for certain trades. In other trades, as will be observed, the case is more doubtful, and it will require some time and careful investigation before a full and complete knowledge of all the circumstances can be arrived at.

In connection with the question of cost there arises another—and that is, as to the *durability* of steel compared with iron. This is a branch of the subject of considerable importance, and is being much discussed at present. To show the extent to which many are interested on this point, I may mention that since a short paragraph appeared recently in the Press relating to the alleged rapid deterioration of torpedo boats built of steel, I have had numerous inquiries in reference to this subject, not only from many interested in it in this country, but also from abroad.

I can quite understand its being desirable to use gun-metal or bronze in preference to either steel or iron for light swift torpedo boats, without drawing the conclusion that steel deteriorates much faster than iron; but this latter is an impression which has somehow got abroad from the paragraph in question, and I should therefore not be sorry to hear a few words on the subject from one or other of our Admiralty friends, as they have doubtless made experiments and careful observations on this subject.

What information I have gained of the comparative deterioration of steel and iron from oxidation, is not such as to warrant the opinion which appears to be entertained by some that steel deteriorates much more rapidly than iron when used for shipbuilding.

The experience which has been gained of the performances of actual vessels built of steel cannot, therefore, fail to be of much value on this point. I have endeavoured to obtain information relative to vessels built of this material which have been the longest in existence. A striking illustration is that of a paddle steamer, which was built on the Clyde in 1859, for the Pacific Steam Navigation Company, and has been employed in actual service up to the present time, and is, perhaps, the oldest steel vessel now afloat. She was examined about four years ago, and the bottom plating from the keel to the water-line was, I understand, found to be in a state of excellent preservation. In the vicinity of the water-line, where deterioration would naturally be expected, the plates were found to be wasted, but not more than might have been the case under the same circumstances with iron plating.

Another case is that of the steel sailing ship of 1,200 tons before alluded to. This ship has been engaged in general trade to India and elsewhere for the last fourteen years, and I am informed when last surveyed she was not found to have deteriorated even to the extent which would have been experienced in an iron vessel under the same circumstances.

In corroboration of this I may mention that when conversing with Mr. Bessemer very recently on this subject, he informed me that he had made experiments with a view to ascertain the comparative corrosion of steel and iron in nitric acid, and that the results would seem to bear out this experience.

I have, it is true, heard of light-draught river boats, built of steel, deteriorating rapidly, but have not yet been able to clear my mind of a suspicion that either the speciality of the cargo, or the nature of the waters navigated, or some such surrounding circumstances, such as carelessness, might have aggravated the wasting alleged to have taken place in them.

I may mention also that there are two steamers over 1,600 tons, at present running between this country and the Continent, which are built of steel. They were built in 1865 and have therefore been afloat the last thirteen years. Other cases might be mentioned of steel vessels which have been running for some years without leading to the conclusion that there is more rapid deterioration in steel than in iron, if the vessels be properly coated and attended to.

At the same time, owing to the smaller comparative scantlings, it is a matter of greater importance in steel than in iron ships, and having in mind the evils arising from negligence in iron vessels, the attention of shipowners cannot be too strongly drawn to the false economy of running their vessels too continuously instead of placing them in dry dock at fitting intervals, so that the surfaces of plating can be properly examined, scraped and painted when found necessary. By a due regard to this, whether the vessels be of iron or steel, my experience leads me to the conclusion that often much unnecessary outlay might be avoided, and the cost of detention and coating would be far more than compensated for by the durability of the vessels.

Many other points, and doubtless new ones will arise in any general application of this material, and these we must be prepared to meet and overcome, and I feel sure nothing will be wanting on the part of the shipbuilders of this country in adapting their appliances and modifying their practice to suit the requirements of any advance in the art of shipbuilding, or in the material to be employed by them. If steel is to replace iron in the immediate future, I need not say the stride will be an enormous one, and great changes may have to follow, but I nevertheless look forward to such changes without misgivings, for I know they will be undertaken with the utmost care, and with every endeavour to abide strictly by the teachings of experience, and with a due regard to the principles involved therein.

TABLE I.—TENSILE TESTS OF RIVETED JOINTS OF STEEL AND IRON PLATES.

No.	Thickness of Plates.	Width of Specimen.	DESCRIPTION.	Thickness of Straps.	Diameter of Rivets.	Ultimate Breaking Strain in Tons per Square Inch.	REMARKS.
	in.	in.		in.	in.		
1	$\frac{1}{4}$	$13\frac{3}{8}$	Iron plates .. .. Single iron strap .. .. Iron rivets. Holes punched	$\frac{1}{4}$	$\frac{5}{8}$	23·1	Broke through line of rivet-holes in plate.
2	$\frac{3}{8}$	$13\frac{3}{8}$	Iron plates .. .. Single iron strap .. .. Iron rivets. Holes punched	$\frac{3}{8}$	$\frac{5}{8}$	16·8	Do.
3	$\frac{3}{8}$	$13\frac{3}{8}$	Steel plates not annealed.. Steel strap do. ... Steel rivets . .. . Holes punched	$\frac{3}{8}$	$\frac{5}{8}$	21·6	Rivets sheared.
4	$\frac{15}{32}$	$16\frac{1}{4}$	Steel plates annealed after punching .. .. .. Stoel strap annealed after punching .. .. .. Steel rivets.. .. .. .. Holes punched	$\frac{15}{32}$	$\frac{3}{4}$	22·9	Broke through rivet-holes in plate.
5	$\frac{15}{32}$	$16\frac{1}{8}$	Iron plates .. .. Iron strap, single .. .. Iron rivets .. .. Holes punched	$\frac{17}{32}$	$\frac{3}{4}$	16·9	Broke through line of rivet-holes in the strap.

TABLE I.—*Continued.*

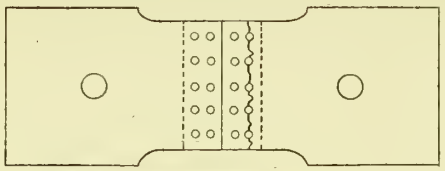
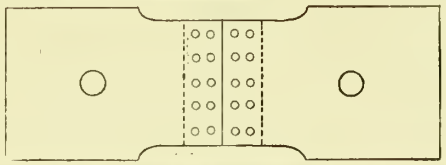
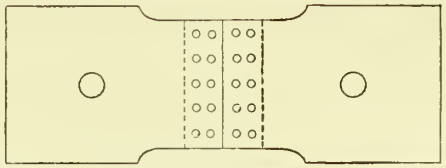
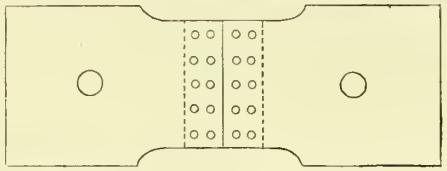
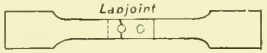
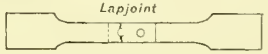
No.	Thickness of Plates.	Width of Specimen.	DESCRIPTION.	Thickness of Straps.	Diameter of Rivets.	Ultimate Breaking Strain in Tons per Square Inch.	REMARKS.
	in.	in.		in.	in.		
6	$\frac{1}{2}$	16	Iron plates .. .. Iron strap .. .. Iron rivets .. .. Holes punched .. .. .. 	$\frac{1}{2}$	$\frac{3}{4}$	15	Broke through line of rivet-holes in plate.
7	$\frac{1}{2}$	$16\frac{1}{8}$	Steel plates not annealed after punching .. .. Steel strap not annealed after punching .. .. Iron rivets .. .. Holes punched .. .. .. 	$\frac{1}{2}$	$\frac{3}{4}$	16·7	Rivets sheared.
8	$\frac{1}{2}$	$15\frac{7}{8}$	Steel plates not annealed after punching .. .. Steel strap not annealed after punching .. .. Steel rivets.. .. .. .. Holes punched .. .. .. 	$\frac{15}{32}$	$\frac{3}{4}$	23·3	Rivets sheared.
9	$\frac{1}{2}$	16	Steel plates annealed after punching .. .. .. Steel strap annealed after punching .. .. .. Iron rivets .. .. Holes punched .. .. .. 	$\frac{1}{2}$	$\frac{3}{4}$	17·1	Rivets sheared.
10	$\frac{3}{8}$	$2\frac{1}{8}$	Steel plates annealed after punching .. .. .. Iron rivets .. .. Holes punched .. .. .. 	—	$\frac{3}{4}$	30·7	Broke plate through a rivet-hole.
11	$\frac{3}{8}$	$2\frac{1}{16}$	Steel plates annealed after punching .. .. .. Steel rivets .. .. Holes punched .. .. .. 	—	$\frac{3}{4}$	31·4	Do.

TABLE I.—*Continued.*

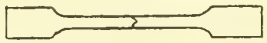
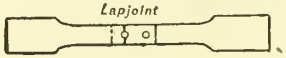
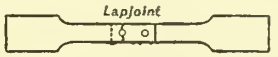
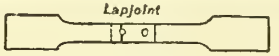
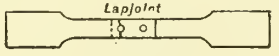
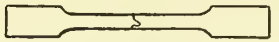
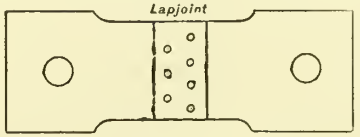
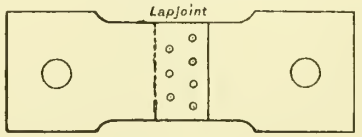
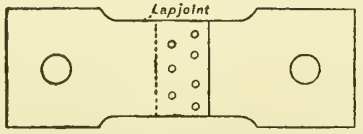
No.	Thickness of Plates.	Width of Specimen.	DESCRIPTION.	Thickness of Straps.	Diameter of Rivets.	Ultimate Breaking Strain in Tons per Square Inch.	REMARKS.
12	$\frac{3}{8}$	$1\frac{1}{2}$	Steel plate, plain .. .. 	—	—	27·5	
13	$\frac{3}{8}$	$2\frac{1}{8}$	Steel plates not annealed after punching .. .. Iron rivets .. .. Holes punched. Edges filed 	—	$\frac{3}{4}$	30·8	Broke plate through a rivet-hole.
14	$\frac{3}{8}$	$2\frac{1}{8}$	Steel plates not annealed after punching .. .. Steel rivets.. .. .. .. Holes punched. Edges filed 	—	$\frac{3}{4}$	30·6	Do.
15	$\frac{3}{8}$	$2\frac{1}{8}$	Steel plates not annealed after punching .. .. Iron rivets .. .. Holes punched. Edges filed 	—	$\frac{3}{4}$	30·7	Do.
16	$\frac{3}{8}$	$2\frac{1}{8}$	Steel plates not annealed after punching .. .. Steel rivets .. .. Holes punched. Edges filed 	—	$\frac{3}{4}$	30·8	Do.
17	$\frac{3}{8}$	$1\frac{1}{2}$	Steel plate—plain .. .. 	—	—	30·8	
18	$\frac{13}{32}$	$12\frac{1}{8}$	Steel plates not annealed.. Steel rivets.. .. .. .. Holes punched .. .. .. 	—	$\frac{13}{16}$	24·1	Rivets sheared.
19	$\frac{13}{32}$	$12\frac{1}{8}$	Steel plates not annealed.. Steel rivets.. .. .. .. Holes drilled .. .. .. 	—	$\frac{13}{16}$	24·25	Do.
20	$\frac{13}{32}$	$12\frac{1}{8}$	Steel plates not annealed.. Iron rivets (Lowmoor) .. Holes punched .. .. .. 	—	$\frac{13}{16}$	19·2	Rivets broke with ragged fractures at or near head or snap.

TABLE I.—*Continued.*

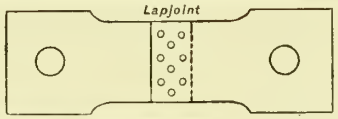
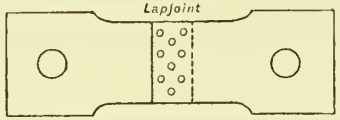
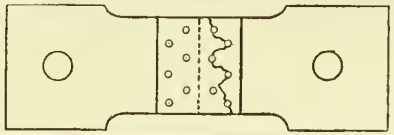
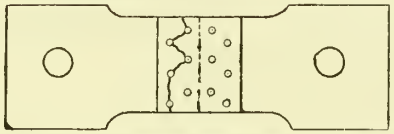
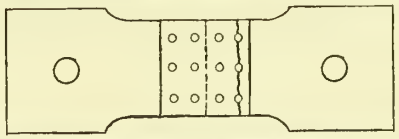
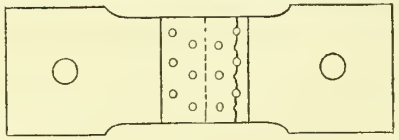
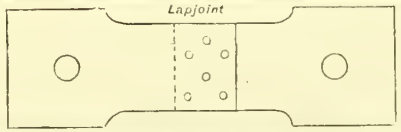
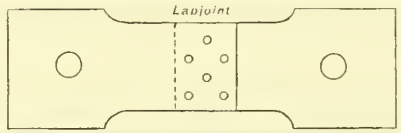
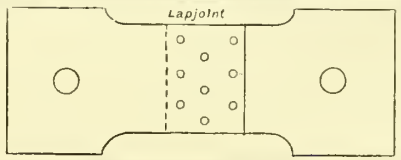
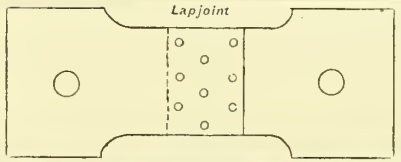
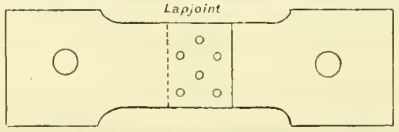
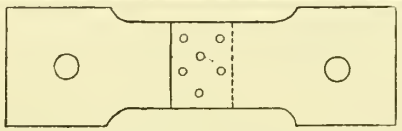
No.	Thickness of Plates.	Width of Specimen.	DESCRIPTION.	Thickness of Straps.	Diameter of Rivets.	Ult'mate Breaking Strain in Tons per Square Inch.	REMARKS.
	in.	in.		in.	in.		
21	$\frac{13}{32}$	1	Steel plate—plain	—	—	29 28·4	
22	$\frac{9}{16}$	10	Steel plates.. .. .. .. Steel rivets.. .. .. .. Holes drilled .. .. .. 	—	$\frac{3}{4}$	27·4	Rivets sheared.
23	$\frac{9}{16}$	10	Steel plates.. .. .. .. Steel rivets.. .. .. .. Holes drilled .. .. .. 	—	$\frac{3}{4}$	26·7	Do.
24	$\frac{11}{16}$	12	Steel plates.. .. .. .. Holes drilled .. .. .. Double butt straps of steel Steel rivets.. .. .. .. 	$\frac{1}{2}$	$1\frac{1}{16}$	24·6	Broke plate through line of rivet-holes.
25	$\frac{11}{16}$	12	Steel plates.. .. .. .. Holes drilled .. .. .. Double butt straps of steel Steel rivets.. .. .. .. 	$\frac{1}{2}$	$1\frac{1}{16}$	23·1	Do.
26	$\frac{11}{16}$	12	Steel plates.. .. .. .. Steel rivets.. .. .. .. Double butt straps of steel Holes drilled .. .. .. 	$\frac{1}{2}$	$1\frac{1}{16}$	28·7	Broke plate through line of rivet-holes.
27	$\frac{23}{32}$	$12\frac{7}{8}$	Steel plate .. .. Steel rivets .. .. .. Double butt straps of steel Holes drilled .. .. .. 	$\frac{9}{16}$	$1\frac{1}{16}$	26·2	Broke plate through line of rivet-holes.

TABLE I.—*Continued.*

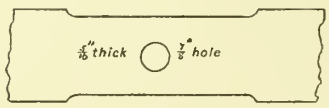
No.	Thickness of Plates.	Width of Specimen.	DESCRIPTION.	Thickness of Straps.	Diameter of Rivets.	Ultimate Breaking Strain in Tons per Square Inch.	REMARKS.
	in.	in.			in.		
28	$\frac{3}{4}$	$11\frac{1}{4}$	Steel plates .. .. .. Steel rivets .. .. .. Holes drilled .. .. .. 	—	$1\frac{1}{16}$	19·7	Rivets sheared.
29	$\frac{3}{4}$	$11\frac{1}{4}$	Steel plates .. .. .. Steel rivets .. .. .. Holes drilled .. .. .. 	—	$1\frac{1}{16}$	19·7	Do.
30	$\frac{3}{4}$	$13\frac{1}{2}$	Steel plates .. .. .. Steel rivets .. .. .. Holes drilled .. .. .. 	—	1	22·2	Rivets sheared.
31	$\frac{3}{4}$	$13\frac{1}{2}$	Steel plates .. .. .. Steel rivets .. .. .. Holes drilled .. .. .. 	—	$1\frac{1}{8}$	21·9	Do.
32	$\frac{3}{4}$	$11\frac{1}{4}$	Steel plates .. .. .. Steel rivets .. .. .. Holes drilled .. .. .. 	—	$1\frac{1}{32}$	22·0	Rivets sheared.
33	$\frac{3}{4}$	$11\frac{1}{4}$	Steel plates .. .. .. Steel rivets .. .. .. Holes drilled .. .. .. 	—	$1\frac{1}{32}$	23·3	Do.

NOTE.—Where the riveting is zigzag, the centre of gravity of the area torn through does not fall in the line of the resultant tension. The stress is, therefore, unequally distributed, and the stress on the material at the point where fracture commences must be greater than the mean stress given in the above Table.

Table III.—IRON: SHOWING THE LOSS OF TENSILE STRENGTH DUE TO PUNCHING.

No.	Dimensions.	Plain Plates, Ultimate Tension.	Ultimate Tension.					Remarks.
		Tons Per Sq. In.	Number and Diameter of Rivet Holes.	Punched and Rimed.	Punched and Annealed.	Punched and not Annealed.		
				Tons Per Sq. In.	Tons Per Sq. In.	Tons Per Sq. In.	Loss from Plain Plate per Cent.	
	Thickness. Width.		Inch.					
1	$\frac{1}{4}$ in. $5\frac{1}{2}$ in.	16·0	Two $\frac{5}{8}$	...	...	14·0	12·5	
2	$\frac{5}{16}$ in. $4\frac{3}{4}$ in.	19·33	Two $\frac{3}{4}$	...	18·25	16·62	14·0	A drilled specimen broke at 17·74 tons.
3	$\frac{3}{8}$ in. $6\frac{3}{4}$ in.	21·7	Two $\frac{3}{4}$	...	...	17·3	20·3	
4	$\frac{7}{16}$ in. 3 in.	21·81	One $\frac{5}{8}$	...	...	17·37	20·3	
5	$\frac{1}{2}$ in. $7\frac{3}{4}$ in.	20·1	Two $\frac{7}{8}$	...	...	16·5	17·9	
6	$\frac{1}{2}$ in. $7\frac{3}{4}$ in.	15·2	Two $\frac{7}{8}$	...	...	14·0	7·8	
7	$\frac{5}{8}$ in. $7\frac{3}{4}$ in.	17·4	Two $\frac{7}{8}$	...	...	16·6	4·5	
8	$\frac{5}{8}$ in. $7\frac{3}{4}$ in.	18·6	Two $\frac{7}{8}$	...	...	14·6	21·5	
9	$\frac{3}{4}$ in. $8\frac{1}{4}$ in.	19·92	Two $\frac{7}{8}$	17·66	19·13	15·59	21·7	Punched with open die.
						15·90	20·0	Ditto ditto close die.
						15·3	23·2	Ditto ditto close die.
10	$\frac{3}{4}$ in. 4 in. ...	24·88	...	...	...	...	...	A drilled specimen stood 19·11 tons per sq. in.
		22·53	One $\frac{7}{8}$	21·17	...	18·19	20·4	A drilled specimen stood 22·57 tons per sq. in.
		22·56	...	...	...	18·93		

Table IV.—Results of Experiments on the Tensile Strength of Samples of the Same Steel Plate Punched with Flat and Patent Spiral Punches Respectively.

Diameter of Hole.	Breaking Weight.		Elongation.		Area of Plate under Tension.	Remarks.
	Actual.	Per Square Inch.	On 2 Inches of Length Across the Holes.	Per Cent.		
In.	lbs.	lbs.				
·885	45,350	63,752	·11	5·5	·7114	Punched with the "flat punch."
·885	45,000	60,318	·23	11·5	·7461	
·895	42,400	57,495	·14	7·	·7375	
·89	37,000	51,287	·03	1·5	·7224	
·89	42,800	60,692	·06	3·	·7052	
·90	45,150	61,047	·07	3·5	·7396	
·895	39,000	55,465	·09	4·5	·7032	
Mean	42,393 or 18·9 tons	58,579 or 26·1 tons.	·104	5·2	·7236	
·885	45,850	63,285	·27	13·5	·7245	Punched with "patent spiral punch."
·88	48,000	67,672	·25	12·5	·7093	
·88	46,200	63,584	·23	11·5	·7266	
·88	44,250	61,254	·12	6·	·7224	
·88	45,500	64,148	·26	13·	·7093	
·895	47,600	66,084	·27	13·5	·7203	
·885	45,600	61,476	·09	4·5	·7418	
Mean	46,143 or 20·6 tons	63,929 or 28·5 tons.	·21	10·6	·7220	

With seven additional experiments that were made, in which two holes were punched in each specimen, one with the "flat punch" and one with the "spiral punch," all the specimens broke through the hole punched with the "flat punch."

The spiral punch referred to is the "patent spiral punch," manufactured by Messrs. Thompson, Sterne & Co.

					Tons.	Tons.
Note.—A $\frac{7}{8}$ oval spiral punch penetrated a $\frac{5}{8}$-in. iron plate at a pressure of					22	and 25.
A $\frac{7}{8}$ oval flat punch	ditto	$\frac{5}{8}$-in.	ditto	ditto	33	and 35.

Table V.—RIGIDITY TESTS.

Comparative Rigidity of $\frac{6}{16}$" Steel and $\frac{7}{16}$" Iron Plates. Both Specimens were 4 feet long × 6" wide. The Bearings were 3 feet apart.

Load.	Deflection of the Iron Plate.	Deflection of the Steel Plate.	Permanent Set in the Iron Plate.	Permanent Set in the Steel Plate.
Cwt.	In.	In.	In.	In.
1	$\frac{1}{8}$	$\frac{3}{32}$	none	none
2	$\frac{1}{4}$	$\frac{7}{32}$	do.	do.
3	$\frac{11}{32}$	$\frac{11}{32}$	trace	do.
4	$\frac{7}{16}$	$\frac{1}{2}$	$\frac{1}{16}$ bare	do.
5	$\frac{9}{16}$	$\frac{21}{32}$	...	trace
6	$\frac{23}{32}$	$\frac{13}{16}$	...	perceptible
7	$\frac{27}{32}$	$1\frac{5}{32}$	...	...
8	$1\frac{3}{32}$	$1\frac{13}{32}$	...	...
9	$1\frac{19}{32}$	$1\frac{23}{32}$	$\frac{21}{32}$	$\frac{1}{2}$ full
10	$2\frac{31}{32}$	$4\frac{15}{16}$	...	...
11	$5\frac{15}{32}$	...	...	...

Permanent Set of the Iron Plate on being entirely released ... ... $6\frac{7}{8}$"

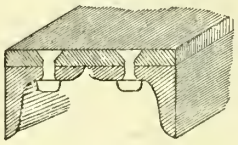
Ditto Steel ditto ... ... $6\frac{9}{16}$"

Table VI.

Comparative Rigidity of Steel and Iron Plates.

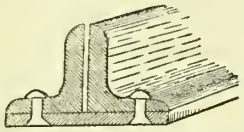
Description.	Load.	Distance of Bearings apart.	Deflection.	Permanent Set.	Elongation.
	lbs.	Feet.	Ins.	Ins.	Ins.
Steel Plate ... ... 4 × $\frac{5}{16}$	987	2	$3\frac{1}{2}$	$2\frac{1}{2}$	...
Iron Plate ... ... 4 × $\frac{3}{8}$	1001	2	$3\frac{3}{8}$	$2\frac{3}{4}$	...
Steel Plate ... ... 4 × $\frac{3}{8}$	1666	2	$3\frac{7}{16}$	$2\frac{11}{16}$	$1\frac{13}{16}$
Iron Plate ... ... 4 × $\frac{1}{2}$	1638	2	$3\frac{7}{16}$	$3\frac{1}{8}$	$\frac{13}{16}$

Table VII.—RIGIDITY TESTS.

Iron and Steel Plates and Angles riveted together thus  *supported at the ends and weighted in the middle.*
Bearings 3 ft. apart.
Pitch of rivets 4 in.

LOAD.	Test No. 1. STEEL. Plate $6\frac{1}{4}$ in. × $\frac{3}{8}$ in. Angles $2\frac{3}{4}$ in. × $2\frac{3}{4}$ in. × $\frac{5}{16}$ in.		Test No. 2. IRON. Plate $6\frac{1}{4}$ in. × $\frac{7}{16}$ in. Angles $2\frac{1}{16}$ in. × $2\frac{1}{16}$ in. × $\frac{3}{8}$ in.		Test No. 5. STEEL. Plate $6\frac{1}{4}$ in. × $\frac{3}{8}$ in. Angles $2\frac{5}{8}$ in. × $2\frac{5}{8}$ in. × $\frac{5}{16}$ in.		Test No. 6. IRON. Plate $6\frac{1}{4}$ in. × $\frac{7}{16}$ in. Angles $2\frac{5}{8}$ in. × $2\frac{5}{8}$ in. × $\frac{3}{8}$ in.		Test No. 9. IRON. Plate $6\frac{1}{4}$ in. × $\frac{3}{8}$ in. Angles $2\frac{5}{8}$ in. × $2\frac{5}{8}$ in. × $\frac{5}{16}$ in.	
	Deflection.	Perm. Set.	Deflection.	Perm. Set.	Deflection.	Perm. Set.	Deflection.	Perm. Set.	Deflection.	Perm. Set.
	In.	In.	In.	In.	In.	In.	In.	In.	In.	In.
4 cwt.	—	—	—	—	·015	·0012	·0185	·005	·025	·010
5 ,,	·0125	·0	·018	·0015	·0166	·004	·025	·005	·0275	·0108
7 ,,	·021	·0057	·025	·0057	·022	·0057	·0265	·0058	·036	·0111
10 ,,	·037	·009	·038	·0112	·032	·008	·0399	·008	·044	·0116
15 ,,	·052	·013	·057	·0190	·048	·012	·056	·0112	·063	·0165
20 ,,	·065	·016	·075	·0255	·063	·0165	·078	·014	·086	·018
25 ,,	·084	·021	·085	·0256	·078	·0218	·090	·0168	·098	·0215
30 ,,	·096	·025	·100	·0257	·084	·0255	·100	·021	·118	·0235
35 ,,	·107	·027	·107	·026	·107	·029	·117	·022	·135	·0255
40 ,,	·120	·032	·111	·026	·119	·031	·136	·023	·140	·027
45 ,,	·132	·035	·118	·027	·130	·033	·140	·026	·155	·0315
50 ,,	·142	·039	·130	·027	·142	·038	·155	·027	·167	·035
55 ,,	·159	·041	·138	·028	·159	·040	·160	·0315	·175	·040
60 ,,	·170	·048	·144	·031	·166	·043	·180	·033	·200	·044
65 ,,	·190	·051	·157	·031	·188	·051	·200	·042	·210	·058
70 ,,	·209	·056	·166	·035	·200	·056	·215	·050	·240	·068
80 ,,	·240	·067	·180	·038	·240	·070	·260	·073	·335	·166
90 ,,	·280	·080	·200	·040	·310	·111	·330	·130	·530	·305
100 ,,	·330	·130	·228	·051	·390	·150	·430	·210	·770	·490
110 ,,	·460	·231	·290	·080	·550	·305	·570	·330	·97	·75
120 ,,	·648	·383	·335	·158	·770	·555	·750	·480	1·31	1·08
130 ,,	·840	·580	·440	·220	1·02	·73	·96	·720	1·87	1·63
140 ,,	1·46	1·20	·590	·37	1·66	1·35	1·18	·960	Did not carry $6\frac{3}{4}$ tons. Plate broke through rivet-holes.	
150 ,,	1·98	1·74	·710	·50	2·44	2·15	1·50	1·22		
160 ,,	Did not carry.		·860	·64	Plate broke through the punched holes. Did not carry $7\frac{3}{4}$ tons.		1·96	Not taken.		
170 ,,			1·04	·80			2·43	,,		
180 ,,			1·24	not taken.			3·14	,,		
190 ,,			1·58	,,			Plate broke through rivet-holes. Did not carry $9\frac{1}{4}$ tons.			
200 ,,			1·85	,,						
210 ,,			2·31	,,						
220 ,,			3·32	,,						
			Plate broke across both punched holes.							

TABLE VIII.—RIGIDITY TESTS.

Iron and Steel Plates and Angles riveted together thus  *supported at the ends and weighted in the middle.*

Bearings 3 ft. apart.

Pitch of rivets 4 in.

LOAD.	TEST No. 3. STEEL. Plate $6\frac{1}{4}$ in. × $\frac{3}{8}$ in. Angles $2\frac{3}{4}$ in. × $2\frac{3}{4}$ in. × $\frac{5}{16}$ in.		TEST No. 4. IRON. Plate $6\frac{1}{4}$ in. × $\frac{7}{16}$ in. Angles $2\frac{1}{16}$ in. × $2\frac{1}{16}$ in. × $\frac{3}{8}$ in.		TEST No. 7. STEEL. Plate $6\frac{1}{4}$ in. × $\frac{3}{8}$ in. Angles $2\frac{5}{8}$ in. × $2\frac{5}{8}$ in. × $\frac{5}{16}$ in.		TEST No. 8. IRON. Plate $6\frac{1}{4}$ in. × $\frac{7}{16}$ in. Angles $2\frac{5}{8}$ in. × $2\frac{5}{8}$ in. × $\frac{3}{8}$ in.		TEST No. 10. IRON. Plate $6\frac{1}{4}$ in. × $\frac{3}{8}$ in. Angles $2\frac{5}{8}$ in. × $2\frac{5}{8}$ in. × $\frac{5}{16}$ in.	
	Deflection.	Perm. Set.	Deflection.	Perm. Set.	Deflection.	Perm. Set.	Deflection.	Perm. Set.	Deflection.	Perm. Set.
	In.	In.	In.	In.	In.	In.	In.	In.	In.	In.
2 cwt.	.....	.....	.....	.....	·009	Perceptbl.	·0031	None	·006	·0012
5 ,,	·019	·0012	·0125	·004	·019	·0013	·0114	Perceptbl.	·0165	·0052
10 ,,	·038	·0057	·032	·0058	·0315	·0027	·023	·00077	·033	·009
15 ,,	·060	·0114	·042	·0058	·051	·012	·036	·005	·046	·011
20 ,,	·075	·015	·056	·0112	·065	·016	·048	·0057	·060	·016
25 ,,	·084	·018	·063	·0112	·070	·0168	·063	·0075	·076	·017
30 ,,	·107	·021	·080	·0112	·096	·0169	·080	·0100	·090	·021
40 ,,	·132	·025	·096	·016	·125	·0210	·098	·0111	·110	·025
50 ,,	·158	·029	·130	·022	·144	·025	·128	·0165	·140	·030
60 ,,	·190	·0315	·140	·0255	·175	·030	·140	·0255	·159	·036
70 ,,	·210	·033	·159	·030	·200	·040	·170	·035	·190	·060
80 ,,	·240	·042	·190	·036	·225	·045	·200	·053	·330	·150
90 ,,	·270	·056	·235	·049	·260	·056	·240	·068	·500	·306
100 ,,	·336	·080	·250	·070	·305	·107	·320	·130	·800	·590
110 ,,	·480	·209	·320	·170	·430	·200	·430	·215	1·18	·95
120 ,,	·690	·400	·460	·210	·665	·405	·590	·350	2·00	1·77
130 ,,	870	·630	·580	·336	1·180	·93	·81	·56	Did not carry $6\frac{3}{4}$ tons. Both Angle irons torn from edge to root.	
140 ,,	1·32	1·02	·750	·490	1·73	1·47	1·18	·92		
150 ,,	1·86	1·61	1·07	·84	Split at 140 cwts. outside edge of angle through the rivet-hole.		1·65	1·39		
160 ,,	3·42	3·08	1·24	1·00			2·51	2·22		
170 ,,	Angle broke through rivet-hole.		1·58	1·30			3·82	not taken		
180 ,,			2·15	not taken			Angle iron did not carry 175 cwt. Torn from edge to root.			
190 ,,			3·10	,,						
200 ,,			5·08	,,						
210 ,,			Did not carry 210 cwts.							

Table IX.—TENSILE STRAINS AND EXTENSIONS OF STEEL PLATES $\frac{1}{2}$ INCH THICK.

No.	Sizes.		Ultimate Stress per Sq. In.	Original Length.	Extension.		Remarks.
	Inches.	Area in Sq. In.	Tons.		Ins.	Per Cent.	
1	1·41 × ·515	·726	27·2	8	2·31	28·9	Mean extension of 4 pieces, each 8 inches in length ... .. 27·5 per cent.
2	1·415 × ·51	·721	27·6	8	2·12	26·5	
3	1·415 × ·51	·721	27·4	8	2·06	25·7	
4	1·415 × ·52	·735	27·0	8	2·31	28·9	
5	1·32 × ·52	·686	27·2	6	1·875	31·2	Mean extension of 4 pieces, each 6 inches in length ... ... 29·4 per cent.
6	1·34 × ·52	·696	27·1	6	1·875	31·2	
7	1·33 × ·525	·698	27·2	6	1·58	26·4	
8	1·35 × ·53	·715	26·9	6	1·735	28·9	
9	1·40 × ·515	·721	27·4	4	1·265	31·6	Mean extension of 4 pieces, each 4 inches in length ... ... 32·0 per cent.
10	1·40 × ·52	·728	27·3	4	1·235	30·8	
11	1·41 × ·52	·733	27·1	4	1·37	34·2	
12	1·415 × ·525	·742	27·2	4	1·26	31·5	
13	1·37 × ·525	·719	27·1	2	·812	40·1	Mean extension of 4 pieces, each 2 inches in length ... .. 37·3 per cent.
14	1·36 × ·515	·700	27·5	2	·735	36·7	
15	1·39 × ·52	·722	27·4	2	·765	38·2	
16	1·41 × ·52	·733	27·1	2	·687	34·3	

Table showing Rates of Extension of Equal Intervals in Length of a Steel Plate $\frac{1}{2}$ inch thick.

	Actual Extension.	Extension.
	Ins.	Per Cent.
1. Extension in the 2-inch adjoining the fracture ...	·921	46·05
2. Ditto next 2-in. of the length of specimen	·527	26·35
3. Ditto next 2-in. ditto ditto	·424	21·2
4. Ditto next 2-in. ditto ditto	·328	16·4

DISCUSSION.

Mr. Henry Morgan (Member of Council): My Lord, I should wish to make just one remark upon the Paper which we have just heard. So far as the Admiralty experience is concerned we have no reason to think that steel will deteriorate faster than iron. The fact that we are building for experiment a torpedo boat of brass, must not be interpreted as implying that for that purpose steel will not last as well as iron, supposing both to be equally taken care of. The Meeting will readily understand that with regard to a plate of steel $\frac{1}{16}$ inch thick, we absolutely cannot afford to lose any, that while taking off $\frac{1}{16}$ inch from iron plates of $\frac{1}{2}$ inch in thickness, would be of comparatively small consequence, it would be of fatal effect on plates only $\frac{1}{16}$ inch thick. That is the reason why we are resorting experimentally to the use of brass in building a torpedo boat.

Mr. J. D'Aguilar Samuda, M.P. (Vice-President): I only desire to say in reference to the Paper put before us that I concur entirely in that which it intends to advocate, namely, a substitution, almost a universal substitution, of steel for iron in shipbuilding, because I believe we are approaching very rapidly to that point. The experiences which are given in this Paper are in many instances very valuable, but there are some matters on which probably some extra experience would be advantageous. First, with reference to the comparative durability of steel and iron. I can go from experience far beyond what this Paper gives us, even the very extended one of the Pacific Navigation in 1859. I can give the Institution an instance of a vessel of 500 tons built by myself in 1865, which I watched very carefully and I found the deterioration there wholly unimportant. Of course the Institution will understand that it is absolutely necessary, both in steel and iron, that each should be properly preserved by painting. If that is neglected, with regard to the thinner description of steel, there would be a worse result than with the thicker description of iron before it was rendered absolutely useless, but I believe, as far as I have been able to observe, that there is considerably less destruction from rust in the steel than in the iron when both are equally submitted to it. Another point which I particularly desire to draw attention to is this: it appears from Mr. Martell's experience, and from the experience of others which he has quoted, that steel is not getting at all a fair chance of being introduced to the extent to which it ought to be from some prevailing impression that seems to exist that steel rivets are not easily and successfully used. In this very vessel which I have alluded to, which has been built now for twenty-four or twenty-five years, there is not a single rivet but what is made of steel, and although I have sent repeatedly—the vessel is working now in the Sea of Azof and the Black Sea—and have had repeated reports from the man in charge of the vessel, not a single instance has been reported to me of any of the rivets having failed. There is no doubt that the failure one would look for from steel would be such a thing as the breaking off of the heads of rivets, but that might be absolutely provided against by carrying out the conical shape of the rivet as is generally done now in the skin-plating of ships, and, if necessary, extending that operation, and counter-sinking, also to the plates in the inside, where that could be done, so as to make the rivet terminate not in an extended head, but in a gradually enlarged diameter. Now I think there is no justification whatever for holding to the idea that you cannot have steel rivets, and the experiments which have been put before us show in every instance how completely you nullify the use of steel by reducing it back again to the strength of the iron, as, in nine cases out of ten, the experiments show that the rivets are the first to give way, and that that is the ultimate strength that you have in your ship. Those are matters which are very important. Now there are two or three things which I think should be explained in this Paper, and perhaps Mr. Martell will be kind enough to explain them when he speaks again. You must recollect that the steel which is used in the present day is a very different material from the steel used formerly, and when steel is referred to as having been used, it is desirable that we should know, both for the benefit and the disadvantage of the steel then produced, what description of steel it was. The steel which I refer to—used in 1854 by myself—was an extremely expensive steel, absolutely cast steel made in the same way as tool steel. That cost at that time £50 a ton, but although it cost that it was no better than steel which you can get at this moment for something like £13 a ton. But then, intermediately between those two prices, there has been quite a different steel used which I do not think can be relied on to the same extent, and that is puddled steel.

From 1862 to 1870 puddled steel was used rather extensively, and I rather think most of the vessels Mr. Martell referred to were built of puddled steel, certainly some of them were. But I can say even with puddled steel a deal of difference existed, and from 1862 to 1865 I myself used puddled steel very extensively in vessels which I built. Five of those are running at this moment; three of them have lasted perfectly, the other two have not, and I believe that a great deal of discredit has arisen to steel in comparison with iron from the fact that steel vessels built about that period did not have the advantage of the best description of material. At any rate, the material which we have to deal with now is totally different; it is a reliable material where you can measure the component parts you put together accurately, and it is very different from what takes place with puddled steel where the man's eye and hand had only to be depended upon for terminating the operation at the time when a sufficient quantity of carbon was discharged from it. You cannot compare puddled steel vessels with those you get from the Bessemer or the Landore steel process which is in use at this moment. I am very glad to hear that the Admiralty maintain the same opinion that they had last year with reference to steel. I think myself the advantages of it are even greater than those put forward in this Paper, because I do not think those advantages are to be measured absolutely by the amount of money, but by something very much further than that, the amount of sustaining quality which we should find from its great ductility whenever it came into positions of very serious difficulty. Be that as it may, I am sure it is a matter which deserves the greatest possible attention of this Institution, because I think with ships and rails, and generally, we are quickly passing from the stage of manufacturing iron into that of manufacturing steel as an entire substitute for it.

Mr. C. Hampden Wigram (Member of Council): My Lord, Mr. Samuda has referred to steel rivets, and I entirely agree with him in what he has said. He will remember that some of the ships he refers to which he built—and we built others at the same time—were built entirely with steel rivets, with the holes counter-sunk on both sides right through the plate. Some of those vessels are running now for the Chatham and Dover Railway, and we had no difficulty in heating or from breaking of the rivets—although we employed the usual rivet boys; we did not spoil more rivets than is usual with iron, and in no way could I see that the steel rivets had deteriorated. Two years afterwards one of these vessels ran against Dover Pier, and knocked her nose completely on one side. She came up to London, and we had to repair her, and so far from the rivets being deteriorated or of inferior quality, we had the greatest possible difficulty in cutting out those rivets. Ordinary steel tools were of no use at all, they broke off in no time, with three or four blows, and we were obliged to get special steel to cut out those rivets, which so convinced me of the advantage of steel for rivets that I cannot conceive why the Admiralty are not able to succeed in themselves adopting it. With regard to the dates, I was not aware that Mr. Martell was referring to the dates at which the vessels were built, but there was one vessel we built of steel, I think, about 1860—I have not the exact date in my mind—and she has been running ever since on the Tigris; therefore you would not imagine that there has not been extra care bestowed on the preservation of her hull, but I believe she is still running, and not a single plate in her bottom has shifted since she was sent out there. I think that shows there is no fear of deterioration where good care is taken to begin with. I am told there is a little difficulty found in regard to welding. I have had no experience in welding steel manufactured by this Martin-Siemens process, but an eminent engineer—I do not see him present, therefore I do not give his name—told me the other day he was trying some experiments with it with a view to constructing boilers, and shutting up the boiler instead of riveting it. He said he could not manage to weld the joints together, and therefore he was obliged instead of following out that method, to come back to the riveted joints. He was desirous to save weight, and was most anxious to have the welded joint. I am afraid Mr. Martell is giving rather too florid a description of the cost. I can only say, not speaking of my own experience but from the opinion of other people as to what the cost is, that I am afraid the increase of cost of a steel ship over an iron ship will be found to be nearly 25 per cent. instead of so small a figure as he puts it. I think I could show Mr. Martell some figures to prove that. I sincerely hope he may be right, because I think nothing tends so much to discourage the use of steel as the cost of it. The only other point which I would mention is this—allusion was made to the Government using copper or yellow metal for shipbuilding. Perhaps it may not be known how very old this is. I believe in the year 1825 or 1826, a vessel was built in the Thames, on the south side, with wooden frames and copper sheets instead of planking for the outside.

Mr. William Henry White (Member of Council): May I be permitted to state why in the Admiralty practice steel rivets have not been used? When the *Iris* was built the greatest thickness of plates used in her construction were ½-inch steel plates, and having made a series of careful experiments before settling on the fastenings of the bottom plating of that ship it was found that ¾-inch Staffordshire iron rivets placed a very small fraction closer in the pitch than they would have been in iron plates gave ample strength for all the butt fastenings. I was present when those experiments were made. I had to do with the calculations, and I know as a matter of fact that there was no objection to the use of iron rivets in the *Iris* except the necessity for a very few more rivets.

Mr. Benjamin Martell (Member of Council): Over what area did you have the plates riveted together?

Mr. W. H. White: Double chain-riveted samples were tested. There was a further reason for the use of Staffordshire iron in that case. A corresponding sample was taken and riveted with Landore rivet steel, which gave splendid results as far as the shearing strength of the rivets was concerned, and also as far as the working. Both samples were taken, and a weight was dropped from a considerable height on to the iron and steel samples. On the whole the iron rivets had rather the best of it, but it was not such a difference as would have been regarded in practice as of very great importance, because the test of dropping this weight was extraordinarily severe, and therefore while I can quite understand that in Mr. Wigram's and in Mr. Samuda's practice steel was used with perfect success, yet I think that it will be easily understood that there was sufficient reason in the *Iris* for not giving up the iron. Nothing would have been gained except the use of a few less rivets. The strength of the skin of the *Iris* is determined by the strength of the weakened sections in the way of the frames, and we could have gained nothing on that except by some special arrangement in framing. As to the rivet tests, Table I. shows, as Mr. Martell has said, that if you use iron rivets in the steel plates you must put them a little closer, or must increase their diameter. That is what has been done in the case of the *Iris*. We have also made some trials with a multiple drill in the direction which Mr. Martell sketched out with regard to ship's plates, but there is some difficulty in making the drill with sufficient elasticity in the play for general work. Those are all the points in connection with steel rivets that I need mention.

Mr. William Denny (Member of Council): I quite agree with Mr. Wigram in what he has said about Mr. Martell taking a rather *couleur de rose* view of the subject, and I would venture to point out that in the comparison between the ship costing £36,000 built of iron, and the same ship built of steel costing £40,000, Mr. Martell has neglected in his calculation of the current expenses a very material item, and that is the depreciation upon the difference of the cost. It is necessary to consider this, because, as must be well known to most of the Members of this Institution, it is a common thing with prudent owners to deduct 10 per cent. per year from the cost of an iron steamer and 7 per cent. from the cost of a sailing ship. If you take the difference between Mr. Martell's two costs, which is £4,500, and depreciate it at the rate at which it would be depreciated for a sailing ship, you have a matter of £315 to be deducted from the £2,220 put down by Mr. Martell. With regard to the tests Mr. Martell has brought before us, I should like him in his reply to tell us whether the iron which was tested against the steel was iron of a superior quality, or whether it was common iron used in common cases by shipbuilders; because if it was iron of a superior and very reliable quality, then to a certain extent it puts the steel at a disadvantage. It seems to have been very good iron. My firm, at the beginning of last year, had the opportunity of building a steel paddle-steamer for the Irrawaddy Flotilla Company of Rangoon. The Directors of the Company up to that time had never built any of their steamers of steel, but entirely of iron, and they were persuaded to build this steamer of steel—so far as the skin-plating and the stringers were concerned—the longitudinal strength was thus entirely of steel, but the transverse framing was of iron. They were not persuaded to do this to get any saving of weight—there was no saving of weight possible, because the scantlings of a steamer built of iron of the same size were reduced as low as they could be before. They built this steamer of steel because they had suffered so severely from many of their steamers being snagged and sunk by trees and stones lying in the bed of the river. This steamer after being built was shipped in pieces to Rangoon. The steel was made to the Admiralty tests, and we were curious to know what the result would be on steel plates of being thrown into the hold of a ship, knocked about on the voyage, and taken out at the end of it. We had shipped several iron steamers before, so that there was a good means of comparison. Only last week we received from the Manager of the Company, in Rangoon, a letter giving a full and most satisfactory account with regard to the steel,

and one which every way confirms the good opinion Mr. Martell has formed of it. He said the steel plates arrived without a single mishap. I think this is very satisfactory, because this although a practical test was a very severe one. These plates went out with their edges punched, and if none of the plates broke in travelling out, then I think it speaks very well for steel. In connection with light-draught steamers, you will, perhaps, permit me to say a word on the reason why steel has not come in so largely for their use as at first sight it would appear it might do. The reason is simply this, that in building an iron light-draught steamer, the limit to which we have reduced the thickness of the parts is the limit due to the power of the resistance of these parts to buckling. Consequently when we come to steel, which for all practical purposes over the same space of framing really buckles as easily as iron, we can go no further. In the case I put before you the one inducement to use the steel was its superior quality to resist snagging and breaking. I would not, however, say that there must be an end to the use of steel for light-draught vessels, because if a much more rigid construction, possibly the closer spacing of very small frames, and the use of partial bulkheads and longitudinals were adopted, we might be able to use steel to advantage in river steamers; and I am perfectly convinced that if steel is to be used with any advantage in large ocean steamers, it can only be by the framing being deepened, or the framing being massed in some way or other. So far as the reductions made by Lloyd's are concerned, I believe, with the present construction, they have gone about as far as it is prudent to go; but I think we may go much further if we adopt a construction more suited to the nature of the material.

Mr. A. C. Kirk (Member): I think we must all feel very much indebted to a society such as Lloyd's for taking up a new subject in this liberal and scientific spirit, and making certain experiments so that they might have a good foundation for what they do with a material like steel, and, still further, for giving us all the *data* of these experiments, so that we may judge for ourselves. Allusion has been made to the bad name which steel got in its early days. That material was really steel, but I think that which sells commercially under the name of steel at present is not steel at all—it is simply the highest class of iron. The experiments to which Mr. Martell referred arose from a conversation with one of the gentlemen at the Admiralty as to what would be the effect upon our forgings in future, seeing that nobody could tell whether the scrap of which they were made was entirely wrought iron or a mixture of iron and steel. I had two bars made, one composed of a mixture of half ordinary iron scrap and steel scrap, and another of steel scrap. The one composed entirely of steel scrap bent double and seemed as good as one forged from a steel ingot could have been; the one partly iron and partly steel was not quite so good, but better than ordinary iron. I take it from that, that the more of this steel there was put in, the better iron it was. It has also been said that steel is apt to be irregular in quality. There is no doubt whatever that steel makers can make it very irregular—they can make it hard and they can make it soft; but in the hands of a good steel maker, I have no hesitation in saying that the material is far more regular than wrought iron, even of first-class qualities. This is what I have found myself in boiler plates, and those of superior qualities too, when I have tested them: when the test plate was taken, I have had samples cut from one end which failed, but when samples have been taken from the other end, very likely they would pass. It is nothing uncommon to find a difference of 10 per cent. between one end of the plate and the other. You seldom find that in a steel plate. There is no doubt whatever, as Mr. Denny said, that Lloyd's have justly weighed the result of the experiments, and that what they are prepared to grant with regard to the ordinary construction of ships is about as much as would be safe. As he remarked, no doubt there is a large field open to shipbuilders now to give their attention to other systems of framing and plating, by which the thickness and the stiffness that was originally got from wrought iron for a little money, because the material was cheap, may now be sought after by some different arrangement in the direction of getting depth with a material that is dear. However, these are speculative matters to which I have no doubt the attention of shipbuilders will be drawn in future, and therefore I will now let them pass. I think it is a pity—but Mr. Martell is quite aware of it—that in taking the stiffness of strips of plate, the experiments have not been extended to strips of plate fixed at the ends. I think it is so great a pity, that I hope Mr. Martell will have experiments tried in that manner before we hold another Meeting, and will give us the full benefit of the result of those experiments. Any one who has seen a piece of steel plate punctured by shot will have seen to what a large extent the tensile strength of steel comes into play in supporting the skin when fixed at the ends; that is to say, after a certain amount of deflection has taken place, it takes a great deal of strength to tear the plate through. I hope Mr. Martell will further carry that subject out. Now, as to testing steel, I am afraid that has been one of the biggest bugbears to its

adoption. Manufacturers naturally dislike the testing. It is not the trouble of testing, because I do not think any rational manufacturer would object to that; but it is from the fact that if from a delivery of plates, a test plate or two are taken and cut up, and these have to be replaced, there is a delay very often through that, and the work, especially the piece work which you have arranged is all upset for want of the missing plates. But if our friends at Lloyd's will allow me to venture to make a suggestion, I think that the right thing would be to throw the *onus* of the quality of the steel on the steel-maker. That the steel-maker, instead of stamping hieroglyphics of various kinds on his plates, should stamp his plates in plain figures, with their tensile strength, it being understood that a certain limit of deviation was to be allowed, say a ton above and below. If that were done, there would then be a representation as to the quality of the steel stamped upon it; and I think our friends at Lloyd's might well employ their time in occasionally checking this maker or that maker, and if they found a maker was in the habit of stamping his plates wrongly, then they would strike him out of their list. I think some such measure as that would prove to be very beneficial.

Mr. E. J. Reed, C.B., F.R.S., M.P. (Vice-President): My Lord, I only wish to call attention to one important point in connection with this extremely valuable Paper. I notice in one instance, which the author of the Paper has given, he takes nearly a total reduction of 20 per cent. from the weight of the iron ship in taking the weight of the steel ship. He takes 1,090 tons as the weight of the iron ship, and 890 tons as the weight of a steel ship of equal power, and the difference is only 18 tons less than the 20 per cent. He only allows the steel ship 18 tons more than the 20 per cent. of the iron ship. If we can do that, then we have made very much greater progress in this matter than I was prepared to believe. I myself have given a good deal of time lately to the designing of steel ships from a commercial point of view, to see how far steel could be adopted for commercial steamers, and I was met by this great difficulty, that although Lloyd's are willing to allow 20 per cent. off the weight of iron in fixing our steel scantlings, that, practically, when you come to design a ship and fix the scantlings of the vessel you cannot take off anything like 20 per cent., and you will see the reason: if you start with a standard and accepted thickness, that you can purchase, but if you take 20 per cent. off that, you frequently have a thickness which you cannot get—you get to minute fractional differences of thickness which you cannot roll to, or at present cannot. What I found was that practically speaking when you take the trouble to go through the whole scantlings of the vessel, and to take the 20 per cent. off which Lloyd's circular allows, you bring the 20 per cent. down to 13 or 14 per cent., and I could not get beyond that point. That being the case, I confess in some instances I was unable to adopt steel when I had many inducements to do so, and should have been delighted to do so, and for no other reason than that. When I find so high an authority as Mr. Martell giving us illustrations in which nearly 20 per cent. is saved, I begin to think I must have neglected some considerations that he has attended to, but I can only say for myself as one anxiously interested in this matter and desirous to see it making the progress which this Paper of Mr. Martell's will enormously encourage, that I should be very glad if he in his reply could show how it is that when you come to take 20 per cent. off all the scantlings of an iron ship you can adhere to the thicknesses which you can obtain in the market and can get rolled. I think you will see all the importance of that point.

Mr. William John (Member of Council): I should like to make one or two remarks with reference to what has fallen from Mr. Reed, and I can speak to this from experience, because at Lloyd's Register we have found the difficulty to which he alludes arising in this way. When a steel ship is submitted for classification with the scantlings marked upon the drawing, and a reduction of 20 per cent. is aimed at, it is easy to see that one of two things must happen. If you have $\frac{10}{16}$ths plating you can take off 20 per cent. as easily as possible by taking off $\frac{2}{16}$ths, but if you are taking 20 per cent. off $\frac{9}{16}$ths you get into an unworkable size and number, and the consequence is you must either go a little above or a little below. If you go a little above the 20 per cent. on each item, you would find when you got right through the section you had a total of 25 or 30 per cent. reduction. If, on the other hand, you give a little on the other side you may reduce it down to 13 or 14 per cent. as Mr. Reed has very properly said. A point to which we give great attention is this, to try by every means in our power where there is a little put on in one direction, in the framing say, to allow a little off the reverse frame, or where there are different thicknesses of plating, if a little more than 20 per cent. is taken off one strake of plating, to have a little less on the next, so as to get as nearly as possible to a general reduction of 20 per cent. I think I can say in several cases the builders themselves have admitted that going over the

whole section we have got quite up to 18 per cent. All I can say is that Mr. Martell and the Committee at Lloyd's, I am quite sure, would desire to meet builders in their attempt wherever there is a fair way of compensating one thing for another to bring it as near a general reduction of 20 per cent. as possible. If you cannot allow something in the top, perhaps you may for an addition in the bottom, and it is right in making this compensation that you should keep as near to the several parts of a ship or the neighbourhood of them as possible, so as to get a proper equivalent for the Rules. There is another point which I will mention, and it is with reference to the riveting. It is quite true that in steel ships, and in more than one instance as we have heard it at these Meetings, steel rivets have been used, and used successfully, and that is a very important fact to remember; but if we find steel rivets used in a ship, and they fail, I would point out this, that twenty successful instances of steel rivets being used in a steel ship would not outweigh one instance where the rivets turned out untrustworthy. It is for reasons of that kind that the Admiralty and the Committee of Lloyd's while not wishing to discourage the use of steel rivets, wish to be as cautious in the matter as possible until they have got to the bottom of the amount of danger that arises from overheating and the special dangers that might be due, or might hereafter be shown to arise from steel rivets. Mr. Kirk has mentioned the question of the rigidity tests. No one can regret more than we do at Lloyd's that we have not a more complete series of rigidity tests, and that we have not had a series of tests with the ends fixed as well as with the ends supported. I admit that there might be differences arising from experiments where they are fixed in the one case and where they are merely supported in the other, but in all these experiments it is a matter of time—it is a matter of cost—and I can only hope that Mr. Kirk himself and many other private shipbuilders will not only look to us for experiments of that kind, but will make experiments for themselves and will give us the results of such experiments. If they do I am sure they will be very valuable and will be appreciated very highly.

Mr. John Macfarlane Gray (Member): My Lord, perhaps it is hardly worth while to make this remark, but since Mr. John seems to have some doubts with regard to steel rivets, I think some valuable information might be gained by communicating with Messrs. Park & Brother, of Pittsburgh, who made some experiments some years ago on a steel boiler. This boiler was 40 inches diameter and 8 feet long, shell $\frac{1}{4}$-inch bare, and in the testing the boiler bellied, and became $3\frac{1}{2}$ inches greater in circumference in the middle of its length, and the failure of the boiler was at a place where they had run short of steel rivets and had put in six iron rivets. The experiment was stopped at 790 pounds pressure per square inch, the pumps being not large enough to make up for the leaking.

Mr. C. H. Wigram: A remark has been made as to the difficulty of reducing 20 per cent. of iron in specified ways. I have a paper in my pocket which I should like to hand in to show how simple it is.*

* The following is the Table handed in by Mr. Wigram.—Ed.

Iron. Thick.		Equals	Steel. Thick.
Eighth of Inches.	Sixteenth of Inches.		
	$\frac{15}{16}$	·937 – 20 per cent.	·75 = $\frac{12}{16}$
$\frac{7}{8}$	$\frac{14}{16}$	·875 – 20 per cent.	·70 = $\frac{11}{16}$
	$\frac{13}{16}$	·812	·65 = $\frac{10}{16}$
$\frac{3}{4}$	$\frac{12}{16}$	·75	·60 = $\frac{10}{16}$
	$\frac{11}{16}$	·687	·55 = $\frac{9}{16}$
$\frac{5}{8}$	$\frac{10}{16}$	·625	·50 = $\frac{8}{16}$
	$\frac{9}{16}$	·562	·45 = $\frac{7}{16}$
$\frac{1}{2}$	$\frac{8}{16}$	·50	·4 = $\frac{7}{16}$
	$\frac{7}{16}$	·437	·35 = $\frac{6}{16}$
$\frac{3}{8}$	$\frac{6}{16}$	·375	·3

Sir R. Spencer Robinson, K.C.B., F.R.S., Admiral (Vice-President): My Lord, I only wish to say two or three words, because I think the practical part of the question can be dealt with very easily and in very general terms, and does not perhaps require so much detail and so many minute observations as have been laid before us to-day. There is no doubt that the practical details and minute observations made by various Members of this Institution are of very considerable value, and will and must be taken into consideration in working out the great scheme, for it is a great scheme, of substituting steel with enormous increased power over the best qualities of iron that can be got. What I wanted to say, and what occurred to me while listening to the very interesting discussion that we have just had, is that those details are not necessarily objections to the permanent and positive substitution of steel for iron. They are matters of detail and matters of manufacture, and there are so few institutions in this country, as I am told, who have yet gone thoroughly into the subject of manufacturing steel instead of iron, that the observations that have been made, the difficulties that have been suggested by my friend Mr. Reed and others, may possibly and I think will certainly in process of time be overcome, and these legitimate objections for the moment to the difficulty of reducing the scantlings, and of obtaining a given per-centage off the weight of a ship, will disappear as we proceed further in the knowledge of the manufacture of steel, and as more institutions enter upon the investigation of this point than are at present employed upon it. I can only therefore say that, both from the objectors to, and also from the advocates of the use of steel, you will see the enormous increase of power we shall gain by the use of steel amounting to a good deal more than that referred to in Lloyd's Rules. There seems generally to be an impression that 25 per cent. at least is due to the additional strength of steel over iron. That being the case, all I wish is, as far as I can do so by the application of legitimate reasoning, to show that there is every reason in the world for encouraging all those who are connected with the production of ships to use steel, and not to be afraid of the temporary difficulties that its use may offer, but to proceed boldly and firmly in the course pointed out, and I have no doubt in the world that enormous success will attend the development of it.

Mr. Henry Hartley West (Member): I am sure we must all be very much obliged to Mr. Martell for putting this matter before us and giving us such valuable Tables. In reference to some of the tests which have been applied, I should like to have asked a number of questions, but our time being limited I will pass from that and draw attention to one point which seems to me to be of considerable importance. That is a matter which Mr. Kirk brought before us at the Autumn Meeting last year, that in some tests of riveted work that he had made he found that the seat of the rivet in the plate yielded under the strain, crushing up, as it were, the plate behind the rivet. To meet that, probably the best course to adopt would be to increase the rivet area, not by increasing the diameter, but by increasing the number of rivets; for, since the surface under crushing strain only increases in the direct ratio of the diameter of the rivet while the rivet area increases as the square of the diameter, the increase in the *number* of rivets would bring out a better ratio between the area of plate under crushing and the area of rivets under shearing strains, than a corresponding increase in their size would accomplish. The quality of the material is such that I think all of us must receive it with very great satisfaction; and when it is accompanied, as it is in some cases put before us for classification in the Underwriters' Registry, with special arrangements of material and construction it is open to reductions which could not be allowed in the case of ships built in the ordinary way. This matter is one which I dare say Mr. Denny will bring before us in his Paper this evening—I hope so at any rate. In reference to a remark of Mr. Reed's, made this morning, that you cannot make a reduction of any given per-centage because you are stuck fast with your 16th, I hope to show you this evening that it is quite possible to do so.

Dr. Charles W. Siemens (Associate): With reference to the observation that fell from Mr. Reed, as to the difficulty of rolling steel plates to dimensions that would present a reduction of weight equal to 20 per cent., I would mention that when the material for the *Iris* and the *Mercury* were ordered from the Landore Company a wish was expressed by the authorities that the weights of the plates should in no case exceed those specified, but that it would be desirable to make those plates perhaps 2 per cent. less in weight than would follow from the calculation. I believe the Landore Company acted strictly up to that, and that the total weight of the material supplied was just 2 per cent. below that calculated, showing that there really is no difficulty in working by weight instead of dimensions. I would suggest that it would be a far more rational thing to order the plates by weight per square foot, rather than by vulgar fractions of an inch thickness. With regard to riveting, I for one would strongly advocate steel rivets in preference to iron. It is true that at Pembroke the experiments tend rather to show that no

material advantage would be gained by the employment of steel rivets, but at that time the question was hardly sufficiently understood. Now steel has been produced which I think answers its purpose perfectly, and reduces the risk of rivet heads falling off to a minimum. I may mention that at another Institution Mr. Boyd, the Engineer of the Slipway Company, will read a Paper to-day giving the result of the construction of several steel boilers in which steel rivets were employed, and he states in that Paper that not a single rivet gave way or gave any trouble whatever in the manipulation, showing clearly that with a little care difficulties that have been complained of—such as overheating—may be overcome. The advantage of steel riveting over iron is not only in the rivet itself, but it is in a great measure in the plate which has to be cut away to a much less extent, and thus leaves a larger nett area of metal to resist the strain. Then again, if the rivets are put the same distance apart as they would be put in an iron plate 20 per cent. thicker, it is natural that these rivets stand too far apart for this reduced thickness of the plate, and this throws a buckling strain on the plate. I would suggest that in riveting steel plates together, the distance between rivet and rivet should be the same as that which would be adopted if a thin iron plate were used—in fact the reduction should be proportionate—the moment you use one material for the plate and another material for stitching the plate together, there is a disproportion between the two elements introduced which naturally must tend to weaken the whole. Perhaps I may be allowed to say one word before I sit down with regard to corrosion. Certain laboratory experiments that have been tried seem to show that steel corrodes faster than iron, whereas most of the working results that have come to my knowledge seem to show the contrary, and to prove that steel wears longer. We have heard to-day of steel ships, from Mr. Martell himself, that have stood wear and tear exceedingly well. But I have no doubt that some steel may be introduced which is liable to corrode at a greater rate than iron would; and although I perhaps have no right to speak absolutely and definitely on the subject, I believe it is the result of an excess of manganese in that steel, and it would perhaps be well for steel users to turn their attention to that subject. Manganese is an exceedingly convenient agent in order to give to steel, or homogeneous iron, the high degree of ductility which is desirable, but it is by no means a necessary element, because at least the same ductility, and the same strength, may be obtained without an appreciable per-centage of manganese in the material; and my experience, which is somewhat limited as to the wearing quality and resistance to corrosion of the two materials, goes distinctly to prove that with an increase of manganese beyond a very narrow limit the steel becomes more corrosive, does not weld with the same facility, and is not so absolutely uniform as when a little manganese is used.

The PRESIDENT: I shall not presume to add anything in the way of opinion on either side to the very interesting Discussion which we have had. I only wish to explain that I thought it my duty, in consequence of the very important and practical character of this Paper, not to limit the Discussion strictly within the limits we have laid down, but I cannot call on Mr. Martell to offer any remarks he may wish to make in reply, without, in the name of this Meeting, thanking him for this very valuable contribution to our Proceedings.

Mr. B. MARTELL (Member of Council): My Lord, since so much time has been occupied in this Discussion I will endeavour to make my remarks as short as possible, and I think it better to confine myself to the principal points put forward and to discuss them more prominently than the others. Now first with reference to the rivets: no doubt, as Dr. Siemens has said, when you are using steel rivets it becomes necessary to look at them differently from iron, and to endeavour to apportion them in a suitable manner, both as to their diameter and as to the spacing of them. If I remember rightly Dr. Siemens promised us to make some experiments on that subject, and I hope he will see his way to do so. Then further than that, as to the constituents of the material, if information could be ascertained with reference to the best proportion of manganese it would be most useful. I can only say with regard to the steel rivets that were found not to answer quite so well as could be wished, they were rivets made from steel from the Landore Company, and I shall be happy to give Dr. Siemens a little of that steel in order that he may analyse it, and then perhaps he may be able to ascertain how it was they did not turn out so satisfactorily as the other rivets which were used.

Dr. SIEMENS: The same steel was used at the Slipway Company.

Mr. MARTELL: I have stated only what was told me. Perhaps from analysis Dr. Siemens could give us some useful information on the point. I regret that Mr. Laird has not given us the benefit of his experience, because it is very great, on the subject of riveting, as it is a matter of so much importance on

this question. Two ships were built by Mr. Laird which turned out very satisfactorily in every way, and I am sure that a few words from him would be of a great deal of service. Perhaps his Lordship would even now allow it?

The PRESIDENT: I am well aware of the value of Mr. Laird's opinion, but I am afraid that any addition to the Discussion now will scarcely be regular, but as it is the wish of the Meeting that Mr. Laird should say a few words, I can offer no objection.

Mr. HENRY HYNDMAN LAIRD (Member of Council): I wish to state with reference to Mr. Martell's Paper and the Discussion which has taken place, that my firm have within the last year built two steamers of steel, one of steel made by the Bessemer process and the other by the Siemens-Martin process, and in both cases they were riveted entirely with steel rivets. We had no trouble whatever with the riveting. In the larger vessel of about 1000 tons we took very great care in watching the riveting during the time the work was going on, and had very severe tests made, and I do not think we had one instance of a rivet-head flying. In arranging the riveting we adopted the plan that Dr. Siemens stated he thought would be the best, namely—we reduced the diameter of the rivets in proportion to the thickness of the plates, and made the spacing of the holes the same proportion to their diameter as it would be in iron. The only difference made was that we left a slightly greater lap between the edge of the holes and the edge of the plate, because we thought, from experiments, that would to a certain extent remove any danger from loss of strength arising from the punching of the plates. With regard to the reduction of the scantlings, I may say that we went nearly as far as 25 per cent. and did not find any practical difficulty in getting the thicknesses we wanted, because we ordered all the plates by weight, giving the weight per superficial foot, and the makers had no difficulty in carrying out our orders. Both these vessels are fitted with machinery of exceptionally high power in proportion to their displacement, and of high speed, and, so far, we have had the most satisfactory reports of their performance in every way. I can only say that our experiments confirm all the most favourable views taken of the use of steel, and that we feel it must be adopted much more generally than it has been, particularly now that it is regular in quality and can be depended on.

Mr. MARTELL: With reference to Mr. Laird's remarks about taking the weight of iron per foot, there is no doubt that is a practical way of getting at it under some circumstances; but there is this difficulty attending its general adoption, that if you have your vessel inspected by surveyors, and it is wished to know what scantlings are put in the ship, you can ascertain the thickness by the report of the surveyor, because he can take the measurements for himself; but no surveyor can tell by looking at a plate what is the weight of it, and you cannot have it got out to weigh it. That is the difficulty found in taking it by weight. But I may say this, that if the present gradations are found to present great difficulty, we can meet it in this way. We have, for instance, the scantlings of Lloyd's Register translated into three Continental languages. Where they use the metrical system, we have all those Tables in the metrical form, and it is just possible that these sub-divisions may be made in that manner. Instead of taking the divisions which we limit ourselves to in iron, *viz.*:—of the 16ths of an inch, we have gone down in steel to the 32nds of an inch. I do not think we should draw these lines too finely, because if we do make these very fine divisions, it is found perfectly impossible for surveyors without a magnifying glass to go and take the sizes. Still the required reductions for steel can at the present time be made very nearly. We have found no difficulty in coming within 18 or 18½ per cent. The builders themselves have gone very carefully into it, and after making these deductions, we find that the reduction will come to about 18 or 18½ per cent. I dare say what Mr. Reed referred to, took place when we did not adopt that 32nd-inch division which has enabled us to do more than we did before. With regard to riveting, those of experience who have tried it maintain that perfect riveting can be done with steel rivets if you only heat them so as to ensure their being heated uniformly at a proper temperature. The only difficulty is where they are heated in an open furnace by careless boys. Mr. Laird himself went round and tested these rivets in place—he did not take especial care it would appear to see them riveted—whereas Messrs. Thomson tell me they placed rivets of steel and iron in the hands of their boys to heat, without telling them what they were—that they tried a large number, and in no instance did they find any danger arose from over-heating. That is a great practical test of the efficiency to which steel rivets can be brought. The only difficulty that has arisen is whether you can rely on these boys heating the rivets sufficiently, so as not to have too many of them burnt. Messrs. Thomson say they found they are more likely to burn iron than steel. Then Mr. Denny asked with regard to the quality of the iron. This was ordinary ship

iron used in making these tests. With reference to Mr. Samuda's remark, the ship of 1,200 tons was built of Bessemer steel, and the plates were I understand carefully selected. Then with regard to the cost, which I think was referred to by Mr. Wigram, I can only say that what I stated was the actual cost. If he wishes a ship of this kind built, I can place him in the hands of a firm who will be glad to build him a ship at that price this moment. Then Mr. Kirk made a remark with regard to throwing the responsibility on the manufacturers of steel. I can only say that Lloyd's Register Society have done that to this extent, that in their circular they say,—Here is a mark you must have on every plate and angle-iron before we will accept it for vessels to be classed in our register, and the mark that is placed upon it must denote that the materials will stand the tensile strain of from 27 to 31 tons—that every piece and every plate has gone through a temper test showing that if plunged at red heat into water at 82 degrees Fahrenheit you can afterwards bend it double. That is a test that makes the steel manufacturer responsible, and if you find in using this steel it does not stand that, it is only for the shipbuilder to call on the manufacturer and say, How is this? And we know, from what we saw in going round to all the manufactories, that there is a specimen kept of every plate and angle, and the number of it, and on comparison they would be able to tell us the cause and to rectify the mistake. That guarantee in my opinion is far better than Lloyd's Register taking on themselves the responsibility of steel manufacturers. I have to express my thanks for the kindness with which this Paper has been received, and I hope it may lead to other more useful experiments being made.

ON THE COMPARATIVE EFFICIENCY OF SINGLE AND TWIN-SCREW PROPELLERS IN DEEP-DRAUGHT SHIPS.

By W. H. White, Esq., Assistant Constructor of the Navy, Member of Council.

[Read at the Nineteenth Session of the Institution of Naval Architects, 11th April, 1878; the Right Hon. Lord Hampton, G.C.B., D.C.L., President, in the Chair.]

The main purpose of this Paper is to place on record the facts respecting the steam trials of deep-draught twin-screw ships of the Royal Navy, and to compare their performances with those of similar ships propelled by single screws. From this comparison it may be possible to deduce some measure of the relative efficiency, as propellers, of single and twin screws; and the discussion will probably have a practical interest for shipbuilders and shipowners generally.

The opinion appears to be generally entertained that in deep-draught ships it is preferable to employ a single screw, because any assigned speed can be attained with a smaller engine-power than would be required with twin screws. This opinion is based rather upon *à priori* reasoning than on actual experience; very few trials having been made with twin screws in deep-draught merchant ships. Moreover, recent experience with ships of war points in the contrary direction; and, after a careful analysis of all the facts which I have been able to collect, my clear conviction is that in vessels of deep draught and large engine-power twin screws have hitherto proved to be more efficient propellers than single screws.

Before proceeding to give the principal *data* upon which this statement is based, I would remark that although trials on the measured mile may not compare in scientific accuracy with experiments like those conducted by Mr. Froude, yet the broad deductions from a large number of such trials may be trusted. Recorded performances on the measured mile include in one result the nett resistance of the ship, the augmentation of the resistance due to the action of the propellers, the efficiency of the engines, and that of the propellers; errors of observation, the influence of tides or currents, and many other circumstances must also be guarded against. It is unquestionable that a separation of these items in the performance, and an analysis of each is the process likely to yield the greatest benefits, and to secure a just appreciation of the real causes of good or bad performance. It is not easy, however, to arrange experiments which shall correctly indicate the value and tendency of each of these constituent parts, as well as eliminate disturbing influences; and for our present purpose it must suffice to have recourse to the results of carefully-conducted measured-mile trials, like those to which I now invite attention.

Table I. contains the particulars of the steam trials of two single-screw ships, and three twin-screw ships, all of which are of equal length. The single screw-ships are sister ships, so also are the other three vessels; and there is a great similarity in form between the two types. Figs. 1 and 2 (Plate I.) illustrate the differences so well that only a few words are needed in further explanation. The *Swiftsure* and *Triumph* have

their iron hulls sheathed over with wood, and are copper-bottomed; the *Iron Duke* and her sisters have iron bottoms. The *Swiftsure* is of deeper draught, to admit of the single screw, and Fig. 1 shows that her midship-section differs from that of the *Iron Duke* chiefly in having a greater rise of floor, and in being wood sheathed. Fig. 2 shows the load water-lines of the two types, and also water-lines 10 feet below the load lines; from these it will be seen that the *Swiftsure* type is somewhat fuller than the *Iron Duke*, especially in the fore body. This greater fullness, no doubt, causes some increase in resistance; but against it may be set the fact that the two single-screw ships have the advantage of coppered bottoms, whereas the twin-screw ships have iron bottoms (with a probably greater co-efficient of friction) and have also the "drag" of the shaft tubes with their supporting struts. On the whole, therefore, it appears fair to suppose that when the two types are driven at equal speeds they will experience resistances approximately proportioned to the *area of their wetted surfaces.* This assumes that their forms are so similar that their *total resistances* for any assigned speed will bear the same ratio to their *frictional resistances*, the possible difference in the co-efficients of friction for copper and painted iron being neglected.*

All these ships attained speeds approaching 14 knots, except the *Vanguard*, which nearly reached 15 knots on her first trial. In order to make the comparison more exact I have estimated the horse-power required to drive all the ships 14 knots, assuming that the resistance varied as the *cube* of the speed within the limits of calculation. This is rather below the true law of variation, and somewhat favours the single-screw ships; but accepting the results, the relative economy of the single and twin screws will appear from the following figures:—

	Mean Value.	
For single-screw ships ...	·249	I.H.P. per square foot of wetted surface.
For twin-screw ships ...	·226	ditto.

Being a clear gain of 11 per cent. in favour of the twin-screw ships.

It may be objected that the Table discloses very marked differences between the performances of the sister ships *Swiftsure* and *Triumph*, or between those of the *Vanguard* and *Iron Duke*, or even between the load and light trials of the *Vanguard.* There is doubtless force in this objection, which in reality only amounts to a confirmation of the views expressed above respecting the results of measured-mile trials. But if the best performance of the single-screw ships is compared with the best for the twin-screw ships, the *Vanguard* (light) gains 19 per cent. upon the *Swiftsure;* or if the *Triumph* is compared with the *Iron Duke*, there is a gain of 8 per cent. in favour of the least successful twin-screw ship. In this last comparison both ships have Griffiths' screws; but the *Iron Duke* would certainly have done better had the pitch of her screw been increased, its revolutions diminished, and the waste work on frictional and other resistances reduced. Hereafter I shall give facts supporting this conclusion; it is worth adding that the performance of the *Iron Duke* is almost identical with that of the *Swiftsure*, in spite of her much greater speed of piston and propellers.

In completion of this comparison it may be stated that all these ships have engines of the same type—simple engines with horizontal cylinders; the average weight of machinery, boilers, &c., for the single-screw engines was about 2·9 cwts. per indicated horse-power; that for the twin-screw engines about 3 cwts.

* A fourth ship of the *Invincible* class, the *Audacious*, is omitted from Table I. Her bottom is zinc-sheathed, and this sheathing was not painted over before the steam trials; consequently its co-efficient of friction was very large as compared with that for the sister ships, and her performance cannot be compared with theirs.

Table II. comprehends the performanees of a number of first-class masted iron-elads, and although there are much greater dissimilarities in form, size, ratio of length to breadth, and types of engines than occur in Table I., it will be possible to obtain some kind of comparison between the single and twin-screw ships.* The figures in the Table expressing the ratio, curved surface of bottom ÷ (displacement) $\frac{2}{3}$, show that there is a considerable resemblance between the forms of the different vessels ; but it is to be remarked that the differences of form are, on the whole, deeidedly adverse to the twin-screw ships. All the single-screw ships, and the *Captain*, were fitted with simple surface-eondensing engines ; the *Alexandra* and *Temeraire* have compound engines. All the ships have Griffiths' two-bladed screws, exeept the *Alexandra*, which has a Mangin screw. These differenees between the engines and propellers, as well as the forms and proportions of the ships, of course affect the performances ; but they can scarcely be considered to aeeount wholly for the very different expenditure of power in the single and twin-screw ships.

To facilitate eomparison all the ships have been assumed to be steaming at an uniform speed of 14·6 knots: the horse-power corresponding to that speed has been estimated from the measured-mile *data* on the hypothesis—known to be a fair assumption—that the resistanee varies as the *cube* of the speed, within the limits of speed considered. Further, I have stated the ratio of these horse-powers to the total wetted surfaees—including bottoms, keel, bilge-keels, shaft-tubes, struts, &c.; and on the whole this is the fairest measure of the expenditure of power. But it must not be overlooked that this measure tells against the twin-screw ships; for the added resistance due to shaft tubes and struts is undoubtedly greater than the mere frictional resistances of the surfaees of these adjunets; and further, in the cases of the *Alexandra* and *Temeraire*, which are fuller formed ships than any of the others, the "wave-making" element of the resistance will, in consequence, be proportionably greater than it is in the finer ships. When the ratio $\frac{\text{Indicated Horse-Power}}{\text{Wetted Surface}}$ is used, as above explained, it is really assumed that the *total resistances* of all the ships compared vary with the *frictional resistances*, which is not strictly true, and which tells particularly against the *Alexandra* and *Temeraire*. Comparing the *Alexandra* and *Temeraire* with the *Hercules*, *Sultan* and *Monarch*, the differenees of form are indicated by Figs. 3 and 4 (Plate I.) Fig. 3 shows the load-line sections. Fig. 4 the forms of the water-lines at mid-draught, and, on inspection, the preceding statements as to the greater fullness of the twin-screw ships will be found to be amply justified.

The *Alexandra*, *Hercules*, and *Sultan*, are of the same length, but the first-named ship is 4 feet 8 inches broader than the other two. Yet she gains $13\frac{1}{2}$ per cent. upon the *Hercules*, and more than 30 per eent. upon the *Sultan*, in the expenditure of power, measured as described above. The *Temeraire* is 40 feet shorter and 3 feet broader than the *Hercules* or *Sultan*, yet she gains nearly 8 per eent. upon the *Hercules* in her expenditure of power, and 26 per eent. upon the *Sultan*. The *Monarch* is a long fine ship as compared with the *Alexandra*, yet the latter requires rather less expenditure of power in proportion to her wetted surface ; and even the *Temeraire*, 45 feet shorter and $4\frac{1}{2}$ feet broader than the *Monarch*, is only 4 per cent. in excess of that ship in her expenditure of power. The *Temeraire*, it must be noted also has her bottom zinc-sheathed. Whatever may be the relative efficiencies of the simple and eompound

* For the facts respecting the *Independencia* I am indebted to the kindness of Mr. E. J. Reed, C.B., M.P., that vessel having been tried before her purchase by the Admiralty. She is now named the *Neptune*.

engines, it is obvious that this remarkable economy of power in the reeent ships must be largely the result of the use of twin screws.

In comparing the *Temeraire* and *Independencia*, a few preliminary observations must be made. The *Independencia* is a somewhat finer ship, and narrower in proportion to her length. She has a coppered bottom, whereas the *Temeraire* has a zinced bottom, painted over before the trials, but probably inferior in smoothness to the copper. In the *Independencia* there are no bilge keels, but in the *Temeraire* deep bilge keels, as well as the shaft tubes and their supporting struts, add to the resistance, and probably add considerably to it. Yet the *Temeraire* gains no less than 26 per cent. upon the *Independencia* in her expenditure of power. The performance of the latter ship will be seen to be almost identical with that of the *Sultan*.

Further, compare the *Captain* and *Monarch*: the former has somewhat the advantage in fineness of form, but against this advantage must be set the drawbacks of the shaft tubes and struts. In this case the engines and screws of both ships are of similar type; the gain in expenditure of power is about 5 per cent. in favour of the *Captain*, even when compared with this exceptionally economical single-screw ship.

The performance of the *Bellerophon*, considering her relatively small size, is very good indeed, but not equal to that of the shorter and bluffer *Temeraire*. The *Bellerophon* gains relatively to the *Hercules* and *Sultan*, not merely because she is rather more finely formed, but because she has a screw of equal diameter, although her engines develope about 25 per cent. less power. This fact suggests the further consideration that since the extreme draught of war ships does not exceed 27 or 27½ feet, there must be considerable difficulties in the way of securing economical performance with single screws in cases where the indicated horse-power has to reach 8,000 horse-power or upwards, unless the general practice in proportioning the diameters of screws to the indicated horse-power is entirely departed from. Increased speeds of screws and of pistons are, of course, possible, but they have their accompanying difficulties and drawbacks; and it seems probable that the marine engineer will have to exercise his skill in devising new types of engines, if the single screw is to hold its place in competition with twin screws. The latter plan enables an ample diameter and disc area of screw-propellers to be obtained for the highest amount of engine power likely to be employed, without exceeding the limits of draught named above, and without any extraordinary speed of propellers and pistons.

In concluding these remarks on Table II., it may be worth mention that if the various differences specified above are disregarded, and the *mean values* obtained for the ratios of indicated horse-powers to the wetted surfaces, they stand as follows:—

		I.H.P.	
For the single-screw ships	...	·31	per square foot of wetted surface.
For the twin-screw ships	...	·26	ditto.

Being a clear gain of 18 per cent. in favour of the twin screws. This is, of course, only a rough mode of comparison.

The excellent performances of the *Devastation* and *Thunderer* on the measured mile furnish still further evidence of the efficiency of twin screws. The *Thunderer* was tried under circumstances of wind and sea which were less favourable than those under which the *Devastation* was tried, and this fact probably accounts for the difference in their performance. Taking the *Devastation's* measured-mile trial it appears that the ratio of the "effective" horse-power, to the "indicated" horse-power was about 42·5 to 100: and it will be remembered that Mr. Froude fixes

about 37 to 100 as a good corresponding ratio for single-screw ships. This indicates about 15 per cent. of gain for the *Devastation* as compared with the average performance of single-screw ships. It is obvious that the absence of rigging and sails in the *Devastation* helps somewhat towards this economy of power: but the twin screws probably help a great deal more. This vessel (285 feet long, and 62¼ feet broad) was driven 13·8 knots with an expenditure of only ·235 horse-power per square foot of wetted surface; and with an expenditure of ·25 horse-power per square foot she could have been driven 14 knots—results which are certainly remarkable when the full form of the ship is considered. The *Dreadnought* also on her light-draught trial did exceedingly well. She is 35 feet longer and 14 inches broader than the *Devastation*, but has virtually the same entrance and run. With an expenditure of ·27 horse-power per square foot of wetted surface she attained a speed of about 14½ knots—a result comparing very favourably with those for the masted ships in Table II. But there is every reason to anticipate that even a better result will be obtained when the *Dreadnought* has her deep-draught trial, the additional immersion of the screws having, as a rule, added to their efficiency in twin-screw ships. The *Alexandra*, for instance, at her first trial on the Maplin, at a mean draught of 24 feet 1 inch, with a displacement of 8,442 tons and a wetted surface of 28,200 square feet, required 8,489 horse-power to drive her at a speed of 15 knots—·301 horse-power per square foot of wetted surface. At her load-draught trial (*see* Table II.) for the same speed the expenditure of power was only ·29 horse-power per square foot of wetted surface. The corresponding trials for the *Temeraire* showed even a more striking difference. At the light-draught the expenditure of power was ·295 horse-power per square foot of wetted surface for a speed of 14·56 knots: whereas at the load-draught the corresponding expenditure was ·279 horse-power for a speed of 14·65 knots, the screws being immersed 14 inches deeper than on the first trial. It must be added that part of this economy of power in the *Temeraire* was undoubtedly due to an increase in the pitch of the screw and to a consequent diminution in the number of revolutions (from 79 to 74) which carried with it a diminution in the waste work of screw frictional and edge resistances, engine friction, &c. The *Vanguard* furnishes an apparent exception to the rule that deeper immersion of the twin-screws adds to their efficiency (*see* Table I). It is only proper to note, however, that the peculiar form of the stern on the *Vanguard* may have led to a sensible increase in the resistance when it was immersed 18 inches deeper than at the earlier trials.

From the foregoing summary of experience with Her Majesty's ships it may safely be affirmed that twin screws have proved more efficient than single screws, as regards economy of power. I do not propose in this Paper to examine into the possible causes of this superiority, further than they suggest themselves in the Tables and the remarks made thereon. The matter is, however, one well deserving enquiry, and will I doubt not receive the benefit of Mr. Froude's experimental investigation. I cannot refrain from noting, however, that the additional resistance incurred in carrying out the shaft-tubes and fixing their struts, is evidently more than compensated for by the efficient action of the screws placed in a good run of water and well clear of the hull. What may be the comparative "augment" of resistance for twin and single screws only experiment can determine.

One other case that has come to my knowledge bearing on the subject, and confirming the previous examples, may here be noted. The *Avni Illah* and *Muini Zaffer* are two Turkish iron-clads, the first built by the Thames Iron Works, and the second by

Messrs. Samuda, both having been engined by Messrs. Ravenhill. They are practically sister ships, I believe, but the former has a single screw, while the latter has twin screws. The *Muini Zaffer* is said to have exceeded 13 knots with 2,555 horse-power and a displacement of nearly 2,100 tons, with force of wind 7; whereas the single-screw *Avni Illah* only reached 12 knots with 2,450 horse-power and a displacement about 100 tons greater than that of her sister ship, the force of wind being 5. If the two vessels were made equal in displacement, the *Avni Illah* would have probably required 3,200 horse-power to reach the speed of 13 knots, which the *Muini Zaffer* attained with about 2,500 horse-power—a gain of 28 per cent. for the twin screws. I am not able to complete the comparison for these ships beyond this point, but it is an interesting case, and deserves to be put on record in detail.

Next I have to notice the comparative trials of two ships, which appear, at the first glance, to contradict our experience in the Royal Navy. Table III. gives the facts, for which I am indebted to Mr. Walter Brock, of Denny Brothers, Dumbarton. It is understood that the two ships were practically sister ships; they were, I believe, built and engined by Messrs. Napier. The broad facts of the case are as follows:—The single-screw ship was driven 14·64 knots, with 3,107 horse-power, whereas the twin-screw ship only reached 13·83 knots with 3,793 horse-power. This is certainly a very inferior performance for the twin-screw ship. When the Table is carefully examined, however, a very curious anomaly becomes apparent:—

(1.) The twin screws have an aggregate disc-area more than 40 per cent. in excess of the corresponding area for the single screw; therefore one would expect the twin screws to have the *less* per-centage of slip.

(2.) Instead of having less slip than the single screw the twin screws have 13·8 per cent., as against 5·2 per cent.

Hence it may be inferred that the twin-screws were not well adapted for their work; and their failure ought not to be construed into a condemnation of the use of two screws, but rather into an argument against the form and arrangement of the twin screws in this particular vessel. Moreover, it will be noticed that the types of engines in the two ships differed widely, and tended to make the comparative performances of the ships less trustworthy as a measure of the relative efficiency of single or twin screws. This feature was, however, probably less influential than the inefficiency of the twin screws noted above.

It is not at all improbable that the performance of the *Washington* might have been greatly improved had some other kind of screw been tried. Several cases might be adduced in support of this opinion. The *Invincible*, for example, was first tried with two Mangin screws 16 feet 2 in diameter, and only 17 feet 2 pitch, and attained a speed of $13\frac{3}{4}$ knots, with 5,178 horse-power. Her performance was so much inferior to that of the *Vanguard*, as to lead to a careful comparison of the forms and positions of the screws in the two vessels, the engines being so similar as to leave little room for supposing any important difference to arise in connection therewith. After being fitted with other Mangin screws of the same form as those of the *Vanguard*, and placed about a foot further aft than the first screws, the *Invincible* performed as shown in Table I. Her gain in speed, due entirely to the change in screws, was estimated at 6-10ths of a knot; that is to say, with 5,178 horse-power she would have probably reached 14·4 knots, and with 4,832 horse-power she actually realised 14·093 knots. The increased pitch led to a decrease in the number of revolutions from 81 to 71, and this resulted in a very important

diminution in the waste work of engine friction, &c., as well as of frictional and edge resistance to the motion of the screws. With Mangin screws having large blade-areas this is obviously a matter requiring careful consideration and only to be settled by actual trial. Reverting to the Table III. it will be seen that the *Washington* has an area of surface of her blades of 185 square feet, as against 158 square feet for the *St. Laurent;* and this greater blade-area was making 78 revolutions per minute as against 69 for the single screw. Here we have a fruitful source of "waste work" for the twin screws as compared with the single screw.

The determination of the best forms and positions for twin screws is a matter which will be largely settled by further experience and experiment. It is sometimes forgotten that whereas the single screw has had the great advantage of thirty or forty years' employment and improvement, the use of twin screws is of much more recent date, and their employment in deep-draught ships is only now becoming common. It is scarcely to be anticipated, therefore, that in all cases an unmixed success will be obtained in the first attempt to use twin screws under new conditions. This was not so in the *Invincible*, but the cause of inferior performance was discovered and remedied. Had the *Washington* been similarly experimented with her performance would doubtless have been much improved. The recent trials of Her Majesty's ship *Iris* furnish a still more remarkable illustration of the foregoing statements; and brief reference must be made to them, although it should be understood that the experiments with her propellers are not yet concluded.

The *Iris* is a dispatch vessel, 300 feet in length, 46 feet broad, and 22 feet extreme draught: her load displacement is about 3,700 tons, and the estimated speed 17 to $17\frac{1}{2}$ knots. For a vessel of her comparatively small size and moderate proportions this is obviously an extraordinarily high speed, and it was estimated that the engines must develope at least 7,000 horse-power in order that the speed should be reached. To secure efficient propulsion, without having recourse to exceptional speeds of pistons and propeller, it was therefore necessary to use two screws, the draught not admitting of a sufficiently large single screw if the ordinary practice in proportioning diameter to engine-power was to be followed approximately: and this arrangement was essential even if twin screws had been considered less efficient propellers. When first tried the *Iris* had two four-bladed screws, each $18\frac{1}{2}$ feet in diameter: the joint disc area of the screws was therefore considerably greater in proportion to the engine-power than is common in single-screw ships, and the surface of the screw blades was exceptionally large. The results of the trials with these four-bladed screws are illustrated (so far as speed and power are concerned) by the curve A, Fig. 5; and they were certainly disappointing. The vessel attained a speed of 16·6 knots with 7,500 indicated horse-power and 91 revolutions per minute. It was then arranged, for experimental purposes only, to remove two out of the four blades on each screw, and to make a series of progressive trials, in order to see what improvement would result from a reduction in the blade area. The curve B, Fig. 5, exhibits the results of these trials, and presents a most remarkable contrast to the curve A. The highest power developed on this trial was 4,369 horse-power, the corresponding speed $15\frac{3}{4}$ knots and the revolutions 89. With the four-bladed screws $15\frac{1}{8}$ knots had required 5,250 horse-power, and 4,369 horse-power would have sufficed for $14\frac{1}{3}$ knots only. It was not desirable to press this extemporised two-bladed screw by running at any higher speeds, nor was its form or pitch adapted for use as a two-bladed screw. Enough had been done to show that the performance of the ship could be greatly improved by a modification in her screws, and steps are

now being taken to supply her with suitable screws. What diameter and form of screw will ultimately be adopted is a question to be settled by further experiments.

In some of the published accounts of these trials with the *Iris* an opinion has been expressed that better results would have been attained with a single screw. This opinion is, to say the least, speculative; for there has never yet been a trial with a single-screw ship of the same moderate draught, in which engines of equal power have been employed. It need not be said that moderate draught is of the greatest importance in a despatch vessel; and, accepting this as a fixed condition, it follows that a single screw could not exceed 20 feet in diameter. Its disc area would be 314 square feet, and upon this 7,000 to 7,500 horse-power is to be applied—a ratio of power to disc area which is, I need scarcely say, exceptionally great. Even the torpedo-vessel *Lightning* has a disc area of $23\frac{3}{4}$ square feet for her relatively enormous power of 400 horse-power; and in the *Inconstant* and *Shah* screws of 23 feet diameter are employed for from 7,000 to 7,500 horse-power developed. It is clear, therefore, that if a single screw had been tried in the *Iris* it must have been associated with conditions in the design of the machinery, in the speeds of piston, screw, &c., or in the ratio of pitch to diameter, which have never yet been tried on such a large scale; in fact the trial must have been largely experimental. And, even if success had been achieved with a single screw, the vessel would necessarily have been deprived of many advantages she now possesses in virtue of her twin screws.

The exceptionally fine form of the *Iris* and the large diameter of her screws rendered it necessary to carry the shafts outboard for the unusual distance of 50 feet. To support the tubes through which the shafts are carried two wrought-iron struts are fitted on each side: and these necessary adjuncts to the hull proper add very considerably to the resistance. This fact, of course, tells against the twin screws, and some fittings of the kind are unavoidable, although further experience may lead to arrangements of struts, &c., which will produce less resistance than those now in use. As we have no trials of single-screw ships of similar form and size with the *Iris*, an exact comparison of her performances with those of such ships cannot be made. In all probability, however, if previous practice were conformed to in engines and screw, about 16 knots is the limit of speed at which ships of the same draught with the *Iris* and having a single screw could be economically driven. But, if any such comparison should be attempted at any time, it must be borne in mind that the *Iris*, when steaming 16 knots, is developing only about two-thirds the full power of her engines, and therefore experiencing an unusually large per-centage of waste work on engine friction, &c.

Although no comparison is possible with another single-screw ship, a comparison can be made between the trials of the full-sized ship and those made by Mr. Froude with her model. It would be out of place to discuss the subject here, but I may be permitted to make one statement which seems to have considerable practical importance. The twin screws, placed well clear of the hull, are exceptionally efficient as propellers, and make the ratio of "effective" to indicated horse-power much higher than is usual in single-screw ships. Mr. Froude fixes this ratio at from 37 : 100 to 40 : 100 in good examples of single-screw ships. Taking the $15\frac{3}{4}$ knots speed for the *Iris*, it appears that if the "effective" horse-power is estimated from her total resistance—including shaft-tubes, struts, &c.—its ratio to the indicated horse-power rises to 44 : 100. Even if the "effective" horse-power be estimated from the *resistance of the hull only*, stripped of these adjuncts, the ratio to the indicated horse-power is above 38 : 100. In other words, the superior propelling efficiency of the twin screws makes amends for the

increase of resistance due to shaft tubes, struts, &c., and for the exceptionally large proportion of waste work on the engine-friction due to the engines working at less than full power, even at a speed for which a single screw could work economically under the conditions of present practice, on the draught of water of the *Iris*. If the twin screws thus hold their own at speeds up to 16 knots, they will probably do much better than a single screw at the higher speeds for which the *Iris* is designed, when 50 per cent. more power is to be put upon the screws than is required for 16 knots. The further trials of the ship will be watched with interest by all connected with the construction of steam ships; but so far as the present trials have gone, they decidedly furnish an argument in favour of the use of twin screws.

Apart from the question of their efficiency as propellers twin screws are the source of some advantages, which should certainly be taken into account in comparing them with single screws. These are—

(1.) Greater security against total disablement of the propelling apparatus.
(2.) Greater handiness, and the maintenance of manœuvring power in case of serious damage to the rudder or steering gear.*
(3.) Greater facilities for the water-tight sub-division of the engine room by means of middle-line bulkheads.

The first-named advantage is that which will probably have most weight with shipowners. It is unnecessary for me to cite cases illustrating the serious character of a "break-down" in the machinery of an ocean-going steamer with a single screw and a small sail spread. But it is obvious that the danger increases with the length of the voyage; and that an accident which would be serious to an Atlantic mail steamer might be much more serious if it happened to a vessel engaged in the Australian service. The gain in safety obtained with twin screws would surely be worth having, even if it entailed a somewhat greater expenditure of engine power and loss of carrying power; but I have shown that no such price has to be paid. On the contrary, there is reason to expect some economy of power with twin screws. Their use in merchant ships would, doubtless, be attended with some difficulties and disadvantages; and I have endeavoured to ascertain what are the chief objections, unconnected with propulsion, that are raised against the employment of twin screws. These seem to be as follows:—

(1.) Greater liability of damage to the screws when ships are going into or out of docks, coming alongside wharves, or taking the ground.
(2.) Reduced cargo space, in consequence of a larger engine room and two shaft passages being required.
(3.) Necessity for a larger and more expensive engine-room staff, in consequence of the machinery being duplicated.
(4.) Increase in the weight of the machinery, in proportion to the horse-power developed, as compared with single-screw engines.

Respecting these objections only a few comments will be needed, since they are all matters of fact and experience. There is obviously considerable force in the first objection. More care is requisite to prevent damage to twin screws than is usual with

* With *ordinary* rudders the use of twin screws does not appear to interfere with the efficient action of the rudder when both screws are working ahead, as compared with that in single-screw ships; but experience has shown that *balanced* rudders are not desirable features in twin-screw ships. With steam or mechanical steering gear the use of balanced rudders is, on other grounds, not preferable; so that this feature in the use of twin screws is of comparatively small importance.

single screws. It is worth notice, however, that several years' experience with Her Majesty's ships have shown that without any extraordinary precautions twin screws can be kept efficient. Merchant ships, no doubt, have to sustain rougher usage than ships of the Royal Navy, and their smaller beam is less favourable to the provision of shelter for twin screws. On the other hand, the merchant ships would require screws of smaller diameter in proportion to their load draught than would be necessary in ships of war, because of the comparatively small engine power needed to drive the merchant ships. The smaller diameter of the screws favours their continued immersion as the ships lighten, and also leads to a decrease in the length of the shaft-tubes outside the hull. I find on examination that even the fullest-powered mail steamers would not require a length of shaft-tubes more than one-half as long as those of the *Iris*, and a single strut on each side would suffice to support these tubes. As compared with the *Iris*, therefore, the increase of resistance due to the struts and tubes would be very considerably less in any merchant steamer, and the screws would be much more sheltered. Even if this were not so I would submit that it might be no difficult matter to arrange a protective "guard" or casing for the twin screws of merchant ships, if such a feature should prove necessary. And, in any case, it seems unwise to wholly put aside the proved advantages of twin screws because of this difficulty, which must certainly be surmountable.

As to the effect of twin-screw engines upon the cargo space I can give no opinion; but I have been assured by competent authorities that in most trades the substitution of two-shaft passages for one would produce no serious loss of carrying capacity; and I may add that in war ships this holds good. With twin screws good "square" stowage is obtained, easily accessible from hatchways at the middle line. With a single-shaft passage, only the wing spaces are available, and the passage being at the middle line renders the stowage of the after-hold less easy. Further, it does not seem probable that with compound engines of the inverted cylinder type the use of twin-screw engines need entail any increase in the space assigned to the machinery. If the engines are placed abreast of one another, it seems likely that the length of the engine room may be somewhat less than with single-screw engines of equal power, and the additional athwartship space required might be compensated for by the reduction in length. In the ships of the Royal Navy the engine rooms in the twin-screw ships are, on the whole, shorter than those for single-screw ships with engines of similar type and equal power. For example, the engines of the *Swiftsure* occupy 30 feet of length, whereas those of the twin-screw ship *Vanguard* occupy 28 feet; and the *Bellerophon*, with 6,500 indicated horse-power, has an engine room 40 feet long, as against 36 feet for the *Captain*, with 6,000 horse-power. In recent ships the adoption of the inverted cylinder type of engine has tended to further economise space, transversely as well as longitudinally.

Respecting the third objection I need not say anything: but a few words are necessary as to the fourth. Taking a considerable number of Her Majesty's ships, engined by different firms, I find that for simple engines with horizontal cylinders and surface condensers, the weight per indicated horse-power of the single-screw engines is about 7 per cent. less than that for twin-screw engines. For compound engines, however, the average weights per indicated horse-power are as nearly as possible the same for single and twin-screw ships. These statements must, of course, be considered in connection with the foregoing remarks on the propelling efficiency of single and twin screws. Although engines in the merchant service are heavier in proportion

to their power than those fitted in Her Majesty's ships, this comparison of the weights of single and twin-screw engines will probably hold good; and it certainly contradicts the general assumption that twin-screw engines are necessarily heavier in proportion to their power.

In conclusion, I would add a few general remarks on the employment of twin screws in ocean-going steamers of the mercantile marine. These vessels are very long and narrow even when contrasted with the *Iris;* and I am not forgetful of the fact that their great lengths and fine forms so considerably diminish their resistance that single screws, of ample diameter in proportion to their engine-power, can be employed efficiently on the working draughts of water. If twin screws were used, however, their average performance would probably be better on a long ocean voyage, involving a considerable variation in the draught, than that of single screws; because the twin screws would be of smaller diameter and more deeply immersed. For the same reason *pitching* would be likely to produce less effect upon the performance of the twin screws, than on that of single screws. Rolling motions could scarcely produce any sensible effect on well-immersed twin screws, although their position at some distance out from the middle line places them at some disadvantage, as to angular motion, compared with single screws. On the whole, therefore, it may be concluded, from the above-stated results of experience as well as from general considerations, that the twin screws would have a decided advantage regarded as propellers only.

In order to carry the twin screws well aft, external shaft-tubes and supporting struts are needed. I have already stated that in no existing merchant steamer need these external tubes be more than half as long as those of the *Iris;* and that the additional resistance or "drag" of the tubes and struts must be small as compared with the corresponding feature in the *Iris.* The analysis of the performance of that ship shows that the twin screws more than compensated for this "drag" by their superior efficiency; consequently there need be no apprehension that in mail steamers the corresponding "drag" would cause a loss of speed. The objections that may be raised to the exposure to injury of the shaft-tubes, struts and screws, have already been considered. So also has the practical guarantee against disablement afforded by the use of twin screws. I may leave the judgment as to the relative importance of these two matters in the hands of shipbuilders and shipowners.

Looking to the future of steam navigation, one thing seems certain: greater speeds will be attained than are now reached. It does not seem probable that any considerable increase in fineness of form, or in the ratio of length to breadth, will be adopted in future ships for the purpose of diminishing their resistance. Any increase in the load-draughts is also clearly inadmissible. The greater engine-powers which will probably be used in the swifter ships will consequently have to be applied on a limited draught of water; and hence it may be anticipated that at no very distant date the designs of swift mail steamers will be subject to conditions resembling those sketched above for the *Iris.* The extreme draught will not permit a use of the single screw with a disc area bearing anything like the ordinary ratio to the indicated horse-power; and it will become necessary either to depart from established precedents in the ratio of pitch to diameter of single screws, to adopt twin screws, or to accept greater speeds of pistons and propellers than are now common in large marine engines. At the present moment there is no great urgency in deciding between these rival methods, and I have no wish to attempt a prediction as to the practice of the future. The matter is, however, one well deserving the careful consideration of marine engineers and naval architects.

TABLE I.

		Single Screws.		Twin Screws.			
	Name of ship	*Swiftsure*	*Triumph*	*Vanguard*	*Vanguard*	*Invincible*	*Iron Duke*
	Length between perpendiculars	280 ft.	280 ft.	280 ft.	280 ft.	280 ft.	280 ft.
	Breadth extreme	55 ft.	55 ft.	54 ft.	54 ft.	54 ft.	54 ft.
	Mean draught on trial	24 ft. 9½ in.	25 ft. 7½ in.	22 ft. 6 in.	21·0 ft.	21·0 ft.	21·0 ft.
	Displacement in tons	6,537	6,840	6,076	5,563	5,563	5,563
	Area of immersed midship-section, sq. ft.	1,140	1,186	1,077	996	996	996
	Area of wetted surface, sq. ft.	22,120	22,620	21,750	20,850	20,850	20,850
	Character of bottom	coppered	coppered		Iron, clean	painted	
Screw Propellers.	Description	Griffiths	Griffiths	Mangin	Mangin	Mangin	Griffiths
	Number of blades on each	2	2	4	4	4	2
	Area of surfaces of blades, sq. ft.	137	137	304	304	304	209
	Diameter	20 ft.	20 ft.	16 ft. 2 in.	16 ft. 2 in.	16 ft. 2 in.	16 ft. 6 in.
	Pitch	24 ft. 6 in.	24 ft. 6 in.	20 ft. 9 in.	20 ft. 9 in.	20 ft. 9⅞ in.	19·0 ft.
	Immersion of upper edge	4 ft. 1 in.	5 ft. 1 in.	4 ft. 4 in.	2 ft. 10 in.	3 ft. 5 in.	3 ft. 3 in.
	Area of propeller disc, sq. ft.	314	314	412	412	412	428
	Revolutions per minute on trial	68·4	67·85	72	73·7	70·8	81·2
Trials.	Where tried	Plymouth	Plymouth	Plymouth	Plymouth	Plymouth	Plymouth
	When tried	11 Jan. 1872	19 Mar. 1873	15 Oct. 1870	7 April, 1870	26 Sep. 1870	18 Aug. 1870
	Force of wind	2 to 3	5	2	2 to 3	1	1
	State of sea	Moderate	Smooth	Smooth	Smooth	Smooth	Smooth
	Indicated horse-power	4,913	5,114	5,312	5,366	4,832	4,789
	Speed of ship, in knots	13·755	13·522	14·076	14·944	14·093	13·855
	Slip of screws—per cent.	16·79	17·57	4·6	·93	1·89 (neg.)	8·99
At 14 knots.	Indicated horse-power	5,275	5,875	5,200	4,140	4,710	4,995
	Ditto per square feet of wetted surface	·2385	·2597	·2391	·2	·2259	·2396

Table II.

		Single Screws.					Twin Screws.		
	Name of ship	*Bellerophon*	*Monarch*	*Hercules.*	*Sultan*	*Independencia*	*Captain*	*Alexandra*	*Temeraire*
	Length between perpendiculars	300 ft.	330 ft.	325 ft.	325 ft.	300 ft.	320 ft.	325 ft.	285 ft.
	Breadth extreme	56·0 ft.	57 ft. 6 in.	59 ft.	59 ft.	63 ft.	53 ft. 3 in.	63 ft. 8 in.	62 ft.
	Mean draught on trial	23 ft. 11½ in.	23 ft. 8½ in.	24·8½ ft.	24 ft. 10¾ in.	24 ft. 8 in.	24 ft. 10 in.	26 ft. 1½ in.	27 ft.
	Displacement in tons	7,236	8,070	8,676	8,714	8,950	7,672	9,432	8,571
	Area of immersed midship section, sq. ft.	1,188	1,208	1,313	1,320	1,453	1,176	1,405	1,455
	Area of wetted surface, sq. ft.	25,400	27,450	28,000	28,140	25,430	26,260	29,620	26,900
	Area of curved surface of bottom (exclusive of bilge keel, &c.) ÷ (displacement) ⅔	59·6 ft.	61·4 ft.	60 ft.	60 ft.	58·3 ft.	62 ft.	59·7 ft.	57·2 ft.
	Character of bottom		Iron, clean painted			Coppered	Iron, clean painted		Zinc, clean painted
Screw Propellers.	Description	Griffiths.	Griffiths	Griffiths	Griffiths	Griffiths	Griffiths	Mangin	Griffiths
	Number of blades on each	2	2	2	2	2	2	4	2
	Area of surfaces of blades, sq. ft.	210	254	210	210	136	200	473	263
	Diameter	23 ft. 6 in.	23 ft. 4 in.	23 ft. 6 in.	23 ft. 7 in.	22 ft. 6 in.	17 ft.	21 ft.	20 ft. ½ in.
	Pitch	20 ft. 1 in.	26 ft. 4 in.	24·0 ft.	24 ft. 1 in.	23·0 ft.	21 ft. 8 in.	22 ft. 2¾ in.	22 ft. 6 in.
	Immersion of upper edge	2 ft. 2 in.	1 ft. 4 in.	1 ft. 11½ in.	2 ft. 4 in.	1 ft. 11 in.	4 ft. 10 in.	3 ft. 3 in.	4 ft. 11 in.
	Area of propeller disc, sq. ft.	434	428	434	434	398	454	692	628
	Revolutions per minute, on trial	75	63·6	71·5	71·5	70·5	74·3	64·2	73·8 ft.
Trials.	Where tried	Stokes' Bay	Stokes' Bay	Stokes' Bay	Stokes' Bay	Maplin	Stokes' Bay	Stokes' Bay	Stokes' Bay
	When tried	17 Aug. 1866	17 July 1869	1 Jan. 1869	19 April, 1871	2 Feb. 1878	2 Mar. 1870	28 Feb. 1877	17 Sep. 1877
	Force of wind	5 to 6	1 to 2	2 to 4	4 to 5	...	3 to 4	4	4
	State of Sea	Little Swell	Calm	Smooth	Smooth	...	Smooth	Smooth	Smooth
	Indicated horse-power	6,521	7,842	8,529	8,629	8,832	5,990	8,615	7,516
	Speed of ship, in knots	14·17	14·94	14·69	14·13	14·6	14·24	15	14·65
	Slip of screws—per cent.	4·73	9·65	13·26	16·85	8·75	10·47	6·5 (neg.)	10·5
At 14·6 knots.	Indicated horse-power	7,350	7,151	8,320	9,835	8,832	6,619	7,732	7,413
	Ditto per square feet of wetted surface	·2894	·2651	·2972	·3495	·3473	·2521	·261	·2756

Table III.

		St. Laurent (Single Screw).	*Washington* (Twin Screw).
	Length	...	345 ft.
	Breadth	...	42·8 ft.
	Mean draught on trial	18·11 ft.	17·81 ft.
	Displacement, in tons	4,445	4,474
	Area of immersed midship-section, sq. ft. ...	642	645·8
Screw Propellers.	Description	Griffiths, curved forwards	Griffiths, straight
	Number of blades on each	4	3
	Area of surfaces of blades, sq. ft. ..	158	185
	Diameter	17·717 ft.	15 ft.
	Pitch	22·637 ft.	20·833 ft.
	Area of propeller disc	246 sq. ft.	353 sq. ft.
	Revolutions per minute, on trial	69	78
Engines.	Description	Horizontal, geared	Inverted, direct
	Number of cylinders	2	4
	Diameter of cylinders	86·6 in.	58 in.
	Stroke	4·265 ft.	3 ft.
Trials.	Where tried	Cherbourg	Cherbourg
	When tried	30 Sept. 1866	22 April, 1868
	Indicated horse-power	3,107	3,793
	Speed of ship, in knots	14·64	13·83
	Slip of screws, per cent.	5·2	13·8

ON THE ELEMENTARY RELATION BETWEEN PITCH, SLIP, AND PROPULSIVE EFFICIENCY.

By W. Froude, Esq., M.A., F.R.S., Vice-President.

[Read at the Nineteenth Session of the Institution of Naval Architects, 11th April, 1878; the Right Hon. Lord Hampton, G.C.B., D.C.L., President, in the Chair.]

Speaking generally, one may say that it is in accordance with the prevailing impressions respecting the theory of the screw propulsion, (1.) that in seeking to obtain from the yielding material, water, a reaction adequate to a large propulsive force, it tends to efficiency to employ as large as possible an effective area in the propeller; and (2.) that it tends to give maximum efficiency to this area, whether it be large or small, if we make it operate on the water as squarely to the line of motion as possible, and therefore with as short a pitch as possible, in order to avoid a useless expenditure of power in giving rotational motion to the water acted on. Hence the limitation in diameter of propeller has been regarded as dependent on the space practically available, and the shortness of pitch as dependent on the speed it was convenient or safe to give to the engines, and by other purely practical considerations involved in reference to both conditions.

But even on *primâ faciê* applicable principles, one sees that definite limiting considerations present themselves; indeed "tendencies" are generally but illusive guides, unless we can assign to each its quantitative value. For instance, admitting that slip, whether large or small, involves a proportionate waste of power, the question at once presents itself, "Would unlimited area of propeller be theoretically valuable? "How much do we lose by the limitation of area imposed by mere practical "convenience?" Indeed, a very exaggerated importance is sometimes attached to slip, as though to reduce slip in a given proportion were to reduce the expenditure of power in the same proportion; whereas, assuming that the slip ratio is already, say, 10 per cent., the waste of power occasioned by it is only 10 per cent. of the whole power, and to halve it would only effect a saving of 5 per cent. of the whole; and to halve it again only a saving of $2\frac{1}{2}$ per cent. more; while each of these gains would require, on the simplest calculation, at least a doubled area, so that to save, in this case, $7\frac{1}{2}$ per cent. of the whole power, we should, approximately, need to double the diameter of the propeller; and we have to ask ourselves what would be the other theoretically inevitable consequences of the alteration. And the same remark applies in reference to the similar apparent gain which seems to be inherent in reduction of pitch, as giving squarer sternward pressure to the blades of the propeller; for if (say) we halve the pitch, so as to give a proportionately increased squareness to the pressure, we must nearly double the number of revolutions to maintain the speed of propulsion; here also we

have to ask ourselves what would be the other theoretically inevitable consequences of the alteration.

In both these cases we see at once that there must ensue a great excess of power expended in overcoming the skin friction and other elements of edgeways resistance inherent in the blades, and it becomes necessary to co-relate these losses with the loss by slip. Take the case of a screw 20 feet diameter, making 80 revolutions per minute; the tips of the blades are travelling at a speed of about 50 knots; now the resistance of a surface so short in the line of motion as a screw-blade, even when its surface is quite smooth, is as much as $1\frac{1}{4}$ pounds per foot at 10 knots, and is nearly as the square of the speed, and as each square foot of blade area involves 2 square feet of skin, the resistance of each is over 60 pounds; thus, making some allowance for thickness and bluntness, there is involved in driving it at 50 knots at least 10 indicated horse-power, and collectively the outmost foot of four such blades, each 3 feet wide, would absorb fully 120 indicated horse-power in surface friction: and though the parts of the blade nearer to the root move with proportionately less speed and therefore with less resistance, yet on the other hand screw-blades are generally "rough from the sand," and have probably a still higher co-efficient of frictional resistance. The edgeways resistance offered by the blade is plainly analogous to that caused by its surface friction, and the same method of treatment will clearly apply to both circumstances; and obviously we are here dealing with an absorbent of power which cannot be left out of sight as inconsiderable.

But however confidently on the strength of known data we might assure ourselves of the great loss of power involved in surface friction, we could not thereby arrive at any definite data as to the pattern and dimensions of the screw which would on the whole minimise the waste of power, unless we could bring also into the calculation the co-related propulsive reaction. Now the pressure or reaction of a fluid on an area moving obliquely through it, has not till lately been reduced to a true theoretical solution; and though it had come to be understood that the old law which made the pressure vary as the square of the sine of the obliquity was entirely in error, and that in reality the resistance was pretty certainly in proportion to the simple power of the sine, it is only quite recently that the question has received a sound theoretical solution.

An eminent mathematician of the day, Lord Rayleigh, has determined the law on stream-line principles, rigorously so far as the pressure on the advancing surface is concerned, for a plane relatively narrow in the line of motion. According to his solution, if P be the normal pressure acting on the face of the plane $P = \frac{(4+\pi)\sin\theta}{4+\pi\sin\theta} P'$, where P′ is the pressure of a head due to the speed, acting on the plane, and θ is the angle between the plane and the line of motion.

Lord Rayleigh regards it as a supposition *primâ faciê* admissible, that the water involved in the eddy at the back of the plane will probably possess a pressure equal to that of the undisturbed fluid, the assumption being that the disturbance created in the fluid by the passage of the plane will be obliterated, and no more than obliterated in eddy motion. It appears pretty conclusively, however, by Beaufoy's experiments that, when the plane is moving normally through the water, so that $\theta = 90°$, the resistance actually experienced exceeds P in the ratio of 112 to 96, and it is not improbable that a proportionate excess, beyond P as given by Lord Rayleigh's formula,

will be experienced also when the motion is oblique; and in the calculations I have made I have assumed this to be the case.

As regards surface friction, the experiments I have conducted for the Admiralty show that it varies about as the power 1·85 or 1·9 of the speed; but for convenience we may adhere to the usual expression that it varies as the square of the speed. The co-efficient or frictional force per square foot at unit speed, varies greatly with the length of the plane in the line of motion and with the quality of the surface.

The pressure and the friction may be respectively expressed with sufficient exactness by the equations $P = p\,A\,v^2 \sin\theta$, and $F = f\,A\,v^2$, where p and f are respectively the pressure and the friction per unit of surface, A the area of the plane, v the speed in the line of motion, and θ the angle between the plane and the line of motion; and if we take the forces in pounds, the area in square feet, and the speed in feet per second, the available data suggest 1·7 as the value of p, and 0·008 as the value of f, bearing in mind, as regards the latter figure, that it provides for the circumstance that the area of a screw-blade has a double surface, the back and the face [illegible] priate to [illegible] er, add neasure dealing igation, degree

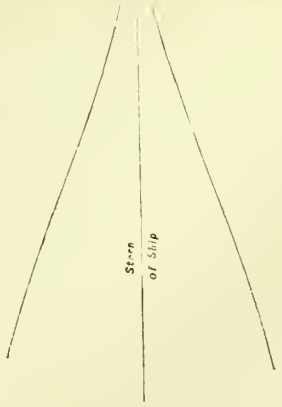
ERRATA.

Page 48, 10th line from bottom, for $\frac{(4+\pi)\sin\theta}{4+\pi\sin\theta}\,P'$, *read* $\frac{2\pi\sin\theta}{4+\pi\sin\theta}\,P'$ moving

Page 50, in Fig. 2, lower section of Diagram, for "speed of ship" *read* "speed of slip." ie to be latively

Last line but one in the same page, for "to the area" *read* "the area."

would be in operation if a series of planes, the edgeway view of one of which is represented on plan by the line A A^1 in the adjoining sketch, were being continuously moved transversely, with a definite steady speed past the ship's stern, actuated by machinery within the ship; each plane in its turn taking up the whole duty and its predecessor being supposed to be annihilated. Under these circumstances if the speed of the ship and the transverse speed of the planes is steady and continuous, a steady propulsive force is developed, and the speed will become steady also. In view of the elementary nature of the conditions to be elucidated, I shall disregard the ship's wake, and imagine the action to take place in wholly undisturbed water.



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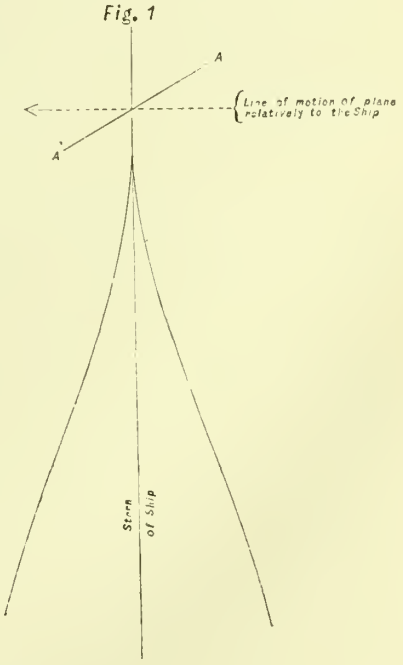
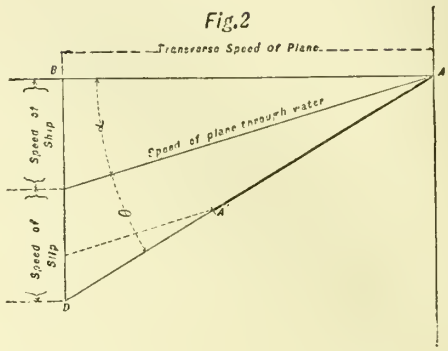
A true conception of the relation between the *modus operandi* of the obliquely moving plane, and the blade of a screw propeller, may be found by imagining the plane to be carried round the screw axis, by a perfectly strong radius of great length relatively to the size of the area, and of indefinitely small thickness, the plane being set obliquely to the plane of rotation, as if it were an unit of area in an extended true spiral surface. Thus viewed we see the action to be in principle the same as that of the action of a fish's tail, or of an oar used in sculling, although the action must be regarded as continuous instead of intermittent. And it is easy to see that the most essential of the dynamic elements of the action are simply those which would be in operation if a series of planes, the edge-way view of one of which is represented on plan by the line A A^1 in the adjoining sketch, were being continuously moved transversely, with a definite steady speed past the ship's stern, actuated by machinery within the ship; each plane in its turn taking up the whole duty and its predecessor being supposed to be annihilated. Under these circumstances if the speed of the ship and the transverse speed of the planes is steady and continuous, a steady propulsive force is developed, and the speed will become steady also. In view of the elementary nature of the conditions to be elucidated, I shall disregard the ship's wake, and imagine the action to take place in wholly undisturbed water.

Fig. 1



By the forward motion of the ship, the motion of the plane which is purely transverse as regards the ship, becomes obliquely forward as regards the water; and the directions and magnitudes of the several elementary motions involved, and the attitude of the plane in relation to them may be understood from the annexed diagram.

Fig.2



As before, the line A A′ being the plane, as seen edgeways in plan, A B is the direction and speed of the plane's transverse motion relatively to the ship; call this speed V: B C is the direction and speed of the ship's forward motion; call this speed v: A C is the direction and speed of the compound motion of the plane through the water; call this speed v'.

The difference between the direction of the plane itself, A D, and the direction of its motion through the water, A C, may be called the slip angle; and the speed of the slip taken account of in a direction parallel to the ship's motion is given by C D; call this speed s.

Call the angle B A C the virtual pitch angle, say, α.
Call the angle C A D the slip angle, say, θ.
Call the angle B A D the actual pitch angle, say, $(\alpha + \theta)$.

Then, in the usual terms of screw propulsion, the slip ratio is $= \frac{\text{C D}}{\text{B D}}$ or $\frac{s}{v + s}$.

If R be the propulsive force required to maintain the ship's speed, then, if we take dimensions in feet, and time in seconds, the useful or effective work in foot-pounds done per second is R v; and the problem to be solved is to apportion the area, and the angles α and θ, so as to make the effective work done bear the greatest ratio to the total work delivered to the propeller.

Besides the work of propulsion, there is the work done in surface friction, and for convenience this may be regarded as resolved into its longitudinal and transverse components. It may be observed that the longitudinal component is manifestly, in effect, an addition to the ship's resistance: so much more propulsive force is to be provided by reason of its operation.

The actions of the several forces with their respective speeds may be deduced and co-related by the regular mathematical methods, so as to produce a fairly complete solution, and the steps of the solution are given in the Appendix: it is sufficient here to mention the leading features of the results.

The area which will drive the ship with a given slip ratio, is directly as the ship's resistance and is inversely as the square of her speed. And since at moderate speeds a ship's resistance may be taken as proportional to the square of her speed, the same area of propeller will at all moderate speeds drive a given ship with the same slip ratio, and areas directly as the squares of the respective dimensions of two similar ships will drive each ship with the same slip ratio, since at such speeds for similar but differently dimensioned well-formed ships to the area of wetted surface in each measures its resistance. At the higher speeds which introduce other elements of resistance, the

slip ratio will become greater with the given propelling area. If two ships have the same resistance at different speeds, the area which will overcome the resistance while maintaining a given slip ratio, will be the less, in the ratio of the squares of the speeds, for the ship which has the higher speed.

The variation of area in terms of varying pitch and slip ratio, admits of no simple verbal statement. The difficulty is the greater since the relation of slip ratio to pitch and slip angle is itself, verbally, not very simple.

Thus far the results accord fairly with ordinary beliefs. The importance of the results shows itself chiefly when they are thrown into a form which expresses the efficiency of the propeller, or the ratio of the effective work realised in the ship's propulsion to the gross work delivered to the propeller.

It is obvious that if friction were zero we might secure perfect efficiency by making area infinite, for we could thus absolutely obliterate slip, whatever the pitch angle. That is to say, if we could disregard the limitation which practical considerations require in the area of the propelling plane, the obliqueness with which it acts on the water would cause no loss of efficiency.

Graphic treatment of the equation of efficiency quickly shows that though the maximum of efficiency is not produced by extending the area of propelling plane so as to minimise slip, yet that, on the other hand, the slip angle which gives maximum efficiency is moderate—that is to say, so moderate that no serious error is introduced by regarding the sine of the angle as equal to the arc. And this change materially simplifies the equation, rendering it easy to treat by the usual method of maxima and minima, so as to determine what slip angle and what pitch angle secure the maximum of efficiency.

We thus are led to the conclusion that the value of θ, which gives the maximum efficiency, is the same whatever be the value of $\alpha + \theta$ the pitch angle. In fact, to make the efficiency a maximum the slip angle must be directly as the square root of the co-efficient of surface friction, and inversely as the square root of the co-efficient of normal pressure; the value is $\theta = \sqrt{\frac{f}{p}}$.

It will be at once seen, from the geometry of the case, that although the slip angle ought thus to have the same value whatever be the pitch angle, the slip ratio which results will be much greater for large pitch angles than for small ones.

A still more curious and interesting conclusion is that which defines the pitch angle of maximum efficiency. If the slip angle be that which gives the maximum efficiency, then to produce the maximum efficiency the propelling plane ought to stand at an angle of 45° with the line of the ship's motion: and this equally happens, whatever be the co-efficients of surface friction, or of normal pressure.

The rationale of the conclusion is, that whereas, if the skin friction of the area is thrown out of the account, the efficiency would be theoretically perfect, as already explained (since the operative area might be indefinitely extended and the pitch would be indifferent), yet when account is taken of surface friction, the pitch ceases to be a matter of indifference, and if the propelling area is so apportioned as to give the slip angle appropriate to the co-efficients of normal pressure and of skin friction, the combination of the conditions in virtue of which the friction diminishes efficiency proves to operate with greater aggregate effect at any other pitch angle than 45°; for if, on the one hand, the pitch angle be increased beyond 45°, the loss is increased in virtue of the

friction of the excess of area then needed to maintain the propulsive force with the given slip faster than it is decreased by the reduced speed at which the friction operates; if, on the other hand, the pitch angle be reduced below 45°, the loss is increased in virtue of the excess of speed with which the friction operates more than it is decreased by the diminution of area necessary to maintain the propulsive force with the given slip.

If the slip angle exceed that which gives the maximum efficiency, the pitch angle must also be increased: if the excess be small, the pitch angle must be increased by the same amount; if the excess be large, the increment of the pitch angle must be still greater.

Taking as the co-efficients of normal pressure and of surface friction those already mentioned, the slip angle of maximum efficiency gives a slip ratio of about $12\frac{1}{2}$ per cent., and the maximum efficiency realised is about 77 per cent. If the area is so apportioned as to give either a greater or a smaller slip ratio the efficiency will be diminished, but the diminution is much more rapid if the slip ratio is diminished than if it is increased, as may be seen by referring to the Diagram (Fig. 3, Plate II.) The Diagram (Fig. 4, Plate II.) shows how the efficiency varies in terms of the pitch angle of which the pitch ratio is the tangent. It will be seen that a given defect of pitch ratio or tangent of pitch angle injures efficiency considerably more than an equal excess of it.

The most salient conclusions to which we are led by this review of the elementary principles on which the efficiency of the screw-propeller depends are (1), that a very much longer pitch than has been commonly adopted is favourable to efficiency: and (2), that instead of its being correct to regard a large amount of slip as a proof of waste of power, the opposite conclusion is the true one. To assert that a screw works with unusually little slip, is to give a proof that it is working with a large waste of power.

In applying to the operation of the twisted surface of an actual screw blade the principles which have been traced in relation to the operation of a plane area, no serious difficulty presents itself: but considerations of considerable intricacy are involved in dealing with the very complex circumstance that the water in which actual screws work has been disturbed by the passage of the ship, and has been converted into a current which more or less rapidly follows her. This circumstance is of very high importance in several respects, but I shall not here refer to it further than to say that in practice, since one certain effect of it is to make the slip ratio appear smaller than it really is, the conclusion that a greatly reduced slip is a proof of waste of power has been largely masked, and the difficulties of an empirical solution of the problem both as regards slip and pitch have been greatly augmented.

It may be useful to observe in conclusion, that whatever may be the effect of the difficulties just referred to as attaching to the extension of the solution from the action of the obliquely propelling plane to that of an actual screw, there are two assertions which may be confidently made in reference to the investigation and its results (1), that the conclusions which have been drawn as regards the plane are in substance incontestable, so far as concerns their character and general bearings; though it is probable that quantitatively they may need some correction on the score of the incomplete exactness of the co-efficients of pressure and of friction, which have been provisionally suggested; and (2), that no theoretical treatment of the action of an actual screw can be sound which does not incorporate and mainly rest on the principles embodied in the treatment of the problem of the plane, and indeed that the character of the results must, in their most essential features, be the same in both cases.

Mathematical Appendix.

Taking the construction given in Fig. 2, p. 50, as the geometrical basis of the solution, A A′ is the propelling plane, the area of which is A. The path of the plane relatively to the ship is transverse to her path and parallel to the line A B, and its speed V. The path of the ship relatively to the water is parallel to B C, and her speed v. The path of the plane relatively to the water is therefore the resultant of the two motions, and is parallel to A C, and its (resultant) speed v'. Call the angle B A C or the "virtual "pitch angle" α; the angle C A D, or the angle of the plane relatively to its path, θ; thus the angle B A D, or the "actual pitch angle," $= \alpha + \theta$. Pressures will be expressed in pounds, speeds in feet per second, areas in square feet, angles in circular measure.

As has already been explained in the text, the normal pressure on the plane area moving through the water with any speed v, on a path forming the angle θ with the plane is $P = p\ A\ v^2 \sin\theta$; (p = about 1·7). The surface friction on an area moving edgeways through the water is $F = f\ A\ v^2$; (for an area having a length in line of motion equal to about the middle of an average screw blade, the co-efficient of skin friction is about 0·004, and since A has two surfaces f = ·008). In the case under consideration—

$$P = p\ A\ V^2 \sec^2\alpha \sin\theta$$
$$F = f\ A\ V^2 \sec^2\alpha$$

The effect of P in the line of the ship's motion = P cos $(\alpha + \theta)$, but from this must be deducted the longitudinal component of the surface friction, which = F sin α.* Thus the nett force available for propulsion = P cos $(\alpha + \theta)$ − F sin α.

This propulsive force must equal the ship's resistance, R. Hence we have the equation R = P cos $(\alpha + \theta)$ − F sin α.

The effective work done is that employed in overcoming the ship's resistance with the ship's actual speed. Call this work U_e; then $U_e = R\ v = R\ V \tan\alpha$; and making the requisite substitutions, and putting k for $\frac{f}{p}$, we obtain the equation

$$U_e = p\ A\ V^3 \sec^2\alpha \tan\alpha \{\cos(\alpha + \theta)\sin\theta - k \sin\alpha\} \quad . \quad . \quad . \quad . \quad . \quad (1.)$$

The gross work done is the transverse component of P + the transverse component of the surface friction, each acting with the speed V; call the gross work U_g,

$$\text{Then } U_g = p\ A\ V^3 \sec^2\alpha \{\sin(\alpha + \theta)\sin\theta + k\cos\alpha\} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (2.)$$

If, for convenience, we prefer to express U_e and U_g in terms of the ship's speed v, instead of in terms of the transverse speed of the plane in relation to the ship or V, remembering that $v = V \tan\alpha$,

$$\text{We have } U_e = p\ A\ v^3 \operatorname{cosec}^2\alpha \{\cos(\alpha + \theta)\sin\theta - k\sin\alpha\} \quad . \quad . \quad . \quad . \quad . \quad . \quad (1a.)$$
$$U_g = p\ A\ v^3 \operatorname{cosec}^2\alpha \cot\alpha \{\sin(\alpha + \theta)\sin\theta + k\cos\alpha\} \quad . \quad . \quad . \quad . \quad (2a.)$$

* It might at first sight be assumed that this component should be taken account of in the direction of the plane, not of the motion of the plane; but it appears on consideration that all the particles to which the plane frictionally imparts motion along its own plane, must accept at the same time the normal component of the plane's motion, and thus its complete resultant path; the force should therefore be estimated as acting in the direction of the resultant motion of which it is the counterpart. [Since the above matter was in type I have been led to doubt the correctness of this assumption, and to lean to what was my original impression, that the component should be taken in the direction of the plane itself; but the assumption simplifies the solution, and the principal results arrived at are not materially affected by the slight error it involves, as the whole work of skin friction is included under either hypothesis. I had traced the solution far enough under my original impression to know that the more complete solution which I retain as already in type is practically admissible.—W. F.]

But also $U_e = R v$, and this substituted in (1*a*) gives the value of A necessary to maintain propulsion.

$$A = \frac{R}{p\, v^2 \operatorname{cosec}^2 \alpha \{\cos(\alpha + \theta) \sin\theta - k \sin\alpha\}} \quad . \quad . \quad . \quad . \quad . \quad . \quad (3.)$$

And substituting this in (2*a*) we have $U_y = R\, v \cot\alpha \dfrac{\sin(\alpha + \theta)\sin\theta + k\cos\alpha}{\cos(\alpha + \theta)\sin\theta - k\sin\alpha}$ . . (2*b*.)

We can now frame the equation of efficiency say E

$$\text{For, } E\left(=\frac{U_e}{U_y}\right) = \tan\alpha \frac{\cos(\alpha + \theta)\sin\theta - k\sin\alpha}{\sin(\alpha + \theta)\sin\theta - k\cos\alpha} \quad . \quad . \quad . \quad . \quad (4.)$$

This equation, if differentiated for θ and tan α respectively, would enable us to determine by the usual process the values of θ and tan α which would respectively and jointly give the greatest value to E: but the differentiation does not lead us to a soluble equation; on the other hand, a few successive graphic solutions of the equation of efficiency show that the value of θ which gives maximum efficiency, is under all ordinary conditions a small one—so small that no appreciable error will result from taking sine $\theta = \theta$, and cos $\theta = 1$. With these substitutions the equation (4) becomes,

$$E = \tan\alpha \frac{\theta\cos\alpha - (\theta^2 + k)\sin\alpha}{\theta\sin\alpha + (\theta^2 + k)\cos\alpha} = \tan\alpha \frac{\theta - (\theta^2 + k)\tan\alpha}{\theta\tan\alpha + (\theta^2 + k)} \quad . \quad . \quad . \quad (4a.)$$

The two differentiations of this equation give respectively the following values of θ and tan α, as the conditions of maximum efficiency.

When θ varies independently

$$\theta = \sqrt{k} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (5.)$$

When tan α varies independently

$$\tan 2\alpha = \frac{\theta}{\theta^2 + k} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (6.)$$

$$\text{or } \tan\alpha = \sqrt{1 + \left(\theta + \frac{k}{\theta}\right)^2} - \left(\theta + \frac{k}{\theta}\right)^* \quad . \quad . \quad . \quad . \quad . \quad (6a.)$$

With this value of tan α it easily follows that—

$$\tan(\alpha + \theta) = \frac{\sqrt{\theta^2 + (\theta^2 + k)^2} - (\theta^2 + k) + \theta\tan\theta}{\theta - \theta\tan\theta\{\sqrt{\theta^2 + (\theta^2 + k)^2} - (\theta^2 + k)\}}$$

And substituting in this from (5) we find as the condition of maximum efficiency on the whole—

$$\tan(\alpha + \theta) = \frac{\sqrt{1 + (2\theta)^2} - 2\theta + \tan\theta}{1 + 2\theta\tan\theta - \tan\theta\sqrt{1 + (2\theta)^2}} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (7.)$$

Now, observing that when θ is small, tan θ does not exceed θ by $\frac{1}{3}\theta^3$, so that when $\theta =$ (say $\frac{1}{5}$), or just exceeds 10°, the difference between the angle and the tangent

* The term $\left(\theta + \frac{k}{\theta}\right)$ is necessarily so small when $\theta = k$, as in equation (5), that the equation is practically equivalent to $\tan\alpha = 1 + \dfrac{\left(\theta + \frac{k}{\theta}\right)^2}{2} - \left(\theta + \frac{k}{\theta}\right)$

is less than $\frac{1}{375}$, we may put $\tan\theta = \theta$, and since within the same scale of approximation $\sqrt{1+(2\theta)^2} = 1 + 2\theta^2$, we have—

$$\tan(\alpha+\theta) = \frac{1-\theta+2\theta^2}{1-\theta+2\theta^2-2\theta^3}, \text{ or in effect} = 1. \quad \ldots\ldots \quad (7a.)$$

Thus in all cases where the due relation between θ and k is maintained so as to secure maximum efficiency, the actual pitch angle which will give the maximum efficiency is 45°.

In view of the probability that slip will be either greater or less than that which corresponds with maximum efficiency, it is desirable to see what modification of pitch angle will tend to minimise the loss of efficiency occasioned by the excess or defect of slip.

This is already deducible from the equation for $\tan\alpha$ in terms of θ, but it is in some respects more convenient to shape the equation in such a form as will show the departure which the angle $(\alpha+\theta)$ should, under the circumstances, make from 45°, which is that which gives the complete maximum of efficiency.

Call the slip angle of maximum efficiency θ' $(=\sqrt{k})$,
And the slip angle θ.
If we call $\alpha = 45° - \gamma$, then $\alpha + \theta = 45° - \gamma + \theta$, and

$$\tan\alpha = \frac{1-\tan\gamma}{1+\tan\gamma}$$

And since we shall not deal with large values of γ, we may with sufficient approximation take $\tan\gamma = \gamma$, so that $\frac{1-\gamma}{1+\gamma} = 1 - 2\gamma + 2\gamma^2$.

Making these substitutions, and putting for $\tan\alpha$ its general value* of maximum efficiency, we have—

$$1 - 2\gamma + 2\gamma^2 = 1 + \frac{\left(\theta+\frac{k}{\theta}\right)^2}{2} - \left(\theta+\frac{k}{\theta}\right)$$

$$\text{Or } \gamma^2 - \gamma = -\frac{\left(\theta+\frac{k}{\theta}\right)^2}{2} + \left(\frac{\theta+\frac{k}{\theta}}{2}\right)^2$$

$$= -\frac{\theta+\frac{'\theta^2}{\theta}}{2} + \left(\frac{\theta+\frac{'\theta^2}{\theta}}{2}\right)^2 \text{ since } k = {}'\theta^2$$

$$\gamma = \tfrac{1}{2} - \sqrt{\tfrac{1}{4}\left\{1 - 4\left(\frac{\theta+\frac{'\theta^2}{\theta}}{2} - \left[\frac{\theta+\frac{'\theta^2}{\theta}}{2}\right]^2\right)\right\}}$$

If we expand the quadratic root by the binomial theorem, and take the first three terms of the series, dropping the third and higher powers of θ, we obtain the result with a very close approximation, at least with such moderate values of θ as are here

* *See* foot-note to equation (6*a*.)

contemplated, since it is desired chiefly to determine the initial change which should be made in $(\alpha + \theta)$ to secure maximum efficiency when θ has differed, but has not differed much, from $'\theta$. Taking the solution thus, and reducing, we obtain—

$$\gamma = \tfrac{1}{2}\left(\theta + \frac{\theta'^2}{\theta}\right)$$

And if we call $\theta = \theta'(1 + h)$ where h is some moderate increment whether positive or negative, we obtain—

$$\gamma = \theta^1\left(1 + \frac{h^2}{2} - \frac{h^3}{2} + \frac{h^4}{2}\,\&c.\right)$$

And for the angle of pitch—

$$(\alpha + \theta)\,(= 45^\circ - \gamma + \theta) = 45^\circ + \theta^1\left(h - \frac{h^2}{2} + \frac{h^3}{2}\,\&c.\right) \quad . \quad . \quad . \quad . \quad . \quad (7b.)$$

That is to say, any moderate alteration of slip angle would demand that to give maximum efficiency, the pitch angle should receive an increment or decrement in effect equal to that of the slip angle.

We shall determine the complete maximum efficiency, say $'E$, by introducing into the equation of efficiency the appropriate values of tan α and θ.

The substitutions give—

$$E' = 1 - 2\sqrt{k} + 2k\,\frac{1 - 2\sqrt{k}\,(1 - 2\sqrt{k} + 2k)}{1 + 2k} \quad . \quad . \quad . \quad . \quad . \quad . \quad (8.)$$

$$\text{Or very approximately} = 1 - 4\sqrt{k} + 8k - 8k\sqrt{k}. \quad . \quad . \quad . \quad (8a.)$$

If we adopt the value of k, which has been suggested, or $k = 0{\cdot}0047$, and introduce it into this equation, we obtain $E' = 0{\cdot}77$; that is to say, if we adopt the most probable values of p and f, and assume the propelling plane to be placed at the most effective pitch angle, and to operate with the most effective slip, 77 per cent. of the work delivered to the plane is the utmost that can be realised in propulsive effect. The efficiency of a screw cannot be so great as this, since only one region of the blade can have the most effective pitch angle.

We can also assign the value of A, say A', which will secure maximum efficiency, the other necessary conditions being complied with.

If the ship's speed be v and her resistance R, then the area

$$A' = \frac{R}{v^2}\,\frac{\sin^2\alpha}{\cos(\alpha + \theta)\sin\theta - k\sin\alpha} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (9.)$$

We may substitute here as the conditions of maximum efficiency $(\alpha + \theta) = 45^\circ$, $\alpha = 45^\circ - \theta$, $\theta = \sqrt{k}$, and making the reductions, the equation approximately becomes—

$$A' = \frac{R}{v^2}\left(\frac{1}{\sqrt{k}} - 1 - 2\sqrt{k}\right) \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (9a.)$$

Which valued out, assuming as before that $k = {\cdot}0047$, gives $A' = \frac{R}{v^2} \times 8{\cdot}9$.

To give a practical conception of the result, we may take the case of a ship whose resistance at 17 knots is 40,000 lbs., which corresponds nearly with the case of H.M.S. *Iris*. Applying these data, the area required is 405 square feet, the slip angle being $3^\circ \cdot\cdot 56' \cdot\cdot 30''$, and the slip ratio $12\frac{3}{4}$ per cent.

The efficiency would be as given above, 77 per cent., but it is deserving of note that in the first place the area required is nearly inversely as the slip assigned, and as efficiency decreases but slowly when the slip is increased beyond that due to the maximum efficiency, a greatly reduced area would be admissible without much loss of efficiency.*

DISCUSSION.

Mr. John Scott Russell, F.R.S. (Vice-President): My Lord, I rise to make some remarks on Mr. White's Paper, in regard to which I feel that both I and all the members of the Profession are extremely and exceptionally indebted to him. A good many years ago I was a member of a Committee of the British Association who communicated with the Admiralty on the desirability of having such experiments very carefully conducted, and extremely carefully analysed. And now I must say that this is one of those Papers and communications to our Profession which answers to all the purposes for which the Committee of the British Association was formed, and for which that Committee applied to the Admiralty. I consider this a most valuable Paper. Now I think, although we are most of us very fond of making our own little experiments and little models, yet after all we derive infinitely more instruction from experiments made with this precision on full-sized ships than we do from small models. In regard to the question of two screws against one, there is one most important point to which all we practical men attach great value, and that is, that two screws propel better than one; and the practical point is this, that in all machinery, especially machinery of war, it is of the greatest consequence to have duplicates, that in every portion of the critical machinery of a ship of war we should have a second stand-by when an accident has happened to one. Two screws give this valuable quality in which one is wanting, therefore there is a great argument in favour of two screws. There is another point in which I think two screws may have a great advantage which has not been alluded to in the Paper. There is in every ship a most favourable place in which to put a screw; and the serious point is, where is that most favourable place. If you have two screws, you may put the screw-propeller considerably forward on the body, and if you have one screw you may put that screw considerably aft on the body; and the question is, whether the two smaller screws placed forward on the body, or the single larger screw placed aft on the body, are the better propellers. Allow me to call your attention to this most important fact. You should study the speed at which that vessel is to be propelled, and its reference to her form. You all know that there is near the stern of the ship what we call a wave of replacement, which has the following qualities—either that it comes in a good position in reference to the screw, or it comes in a bad one; and the question in regard to each ship is, whether you will place the screw immediately under the crest of this wave, or whether you place it in the bad position with the hollow of the wave near it or above it. Now allow me to tell you the cause of this difference. On the crest of that wave the water is going forward in the direction of the ship, and contrary to the slip of the screw. In this wave, in the same manner, at the top the water in the crest is going rapidly forward in the direction of the ship, and consequently is opposed to the screw; therefore, in these two positions the slip of the screw is greatly diminished. But in the

* Experiments, which have been in progress since this Paper has been in type, show conclusively that the decrease of efficiency consequent on increased slip, with screws of ordinary proportion, is scarcely perceptible even when the slip ratio is as large as 30 per cent., with the screw working in undisturbed water. The results so shaped themselves as to point to the conclusion that, for some reason or other, the co-efficient of surface friction began to diminish when the slip ratio became as much as 15 per cent., and was about halved when the slip ratio was 30 per cent.; and as it appeared not improbable that with increasing slip a more or less pronounced eddy might become established at the back of the blade, so as more or less completely to neutralise the friction on that surface, a rough experiment was tried by moving a plane obliquely through the water with various angles of slip, and in a position where the effect could be observed; and in point of fact it appeared that when the angle between the plane and its line of motion was about 10 degrees, the water at its back had assumed the form of an eddy, having nearly the speed of the plane, and that it in fact overran the plane when the angle was increased to 15 degrees.

hollow, on the contrary, the water is going in the opposite direction, and thereby the slip of the screw is greatly increased. In my own opinion, where the ship is properly formed, it is so formed that at the given speed the crest of that wave will be in the plane of the screw, and then there will be a minimum slip; and I think that the efficiency of the twin screws will be found to be very materially dependent on having chosen for them the best place, and where those twin screws have proved a failure it will probably be found to be because they were put in the wrong place. What that place is you all know who have studied the wave system, because you know there is an exact point at which, with a given speed, the crest of the summit of the wave of replacement will be found. The one will be a good form for the twin screw, and the other will be a good form for the single screw. One point more in favour of the double screw is, that in pitching, as the screw is a good deal lower under water, it will not be exposed so much to the inequalities as the other.

Mr. Charles W. Merrifield, F.R.S. (Associate Member of Council): My Lord, I think the Meeting will agree with me that Mr. White's Paper thoroughly deserves the eulogy passed on it by Mr. Scott Russell, as being a thoroughly painstaking investigation of actual facts, and not dealing largely with generalities, but where it does use any, supporting them very carefully by an actual qualitative discussion of the performances of different ships of full size. I think it would be impossible to over-estimate the value of such Papers to this Institution, and to the science of naval architecture. But there is one point in which I was unable to follow my friend, Mr. White, and that is in the application of those figures to the general object of the Paper. As I understood him, he was dissatisfied with the statement commonly made, that because in a vessel of large draught you can get a large propeller area, there is an advantage in vessels of large draught in having a single screw, and for an opposite reason in vessels of small draught in having a double screw. Now being thus very reasonably dissatisfied with a general statement of that kind he has done a very rational and useful service in going into it qualitatively, and examining the relative performances of vessels of deep draught under varied conditions. But when he comes to the general conclusion which is the object of the Paper, and which he deduces from these figures, I am a little unable to follow him in this respect, that when I look to the proportions of the vessels he examines, I find that although these Admiralty vessels are without any exception of deep draught, taken absolutely, yet when I take these vessels relatively to their beam I find they are all vessels of proportionately shallow draught. I find that with scarcely an exception, and I think without an exception, the draught is considerably less than half the beam, in some cases as little as $\frac{2}{5}$ths of the beam. Now, in most cases of deep merchant ships the proportion is quite as often $\frac{3}{5}$ths as one-half the draught. I cannot quite follow Mr. White in his conclusion that because with a vessel of absolutely deep draught, but of relatively shallow draught, the twin-screw propeller is an advantage over the single propeller (which was a conclusion to be expected from the ordinary reasoning applied to the general case), that the twin-screw propeller is on the whole preferable; and it does not seem to me quite possible to make out his case of the general advantage in merchant ships, in which the proportions are different, of having twin screws instead of one, without examining the case where twin screws have been successfully applied to a vessel of deep relative draught—that is to say, something about $\frac{3}{5}$ths of her beam. That is, of course, an important point, which Mr. White will be able to deal with in his reply, but I think it is important that we should not adopt his conclusions without at least paying attention to it.

Mr. E. J. Reed, C.B., F.R.S., M.P. (Vice-President): My Lord, I would wish to make one or two remarks on this Paper, and I would first refer to the *Iris* because I was very glad indeed to see Mr. White bring the *Iris* into this investigation. I believe, without the slightest blame to anybody, she is, with regard to her great object of being a fast ship furnished with twin screws, a signal failure up to this time—that is to say, she is a ship performing nothing like the speed which is due to her power in contrast with other ships. I say that not at all with a view to cast a reflection upon anybody, because I do not think there is anybody to cast a reflection upon. I think the course taken as stated in the Paper was a justification for the Admiralty trying the experiment. It was a great experiment. An enormous speed was desirable from a vessel with moderate dimensions, and from the draught of water which alone could be allowed you could only put a single screw with a diameter out of all proportion to the power to be exerted according to our previous experience. That being the case the Admiralty wisely adopted the twin screws. They put enormous power on them, and the result has thus far been a great failure, the ship showing nothing like the speed intended or expected under ordinary conditions. Therefore, I take it for granted that the *Iris* will be watched by all the Members of this Institution with the deepest

interest, because no doubt her case will prove pregnant, when further experiments have been made upon her, with information which we should very much appreciate. The first experiment that has been made appears to have been to take away the four-bladed screw, and to put two-bladed screws, and the result has been, as I understand it, that with these two-bladed screws, and for a less development of indicated horse-power, the speed hitherto obtained is the maximum that has been secured. So that there is at present in the ship a reserve of horse-power which may be recorded I think at 1,000, but of which the corresponding speed has yet to be got. The Members of this Institution will see in a moment that that is an experiment with a twin-screw ship of the greatest interest and importance, and all the more because of the suggestion of the fact to which Mr. Merrifield referred—namely, that these ships, the results of which we have tabulated, do not present a case analogous to the *Iris*, which is an instance more analogous to mercantile steamers, because her proportions are more like those vessels. These vessels (in Mr. White's Table) are all of very great beam, and consequently, although their draught is great, the proportion of breadth to draught is very considerable. Mr. White came to the conclusion that the one serious objection to twin-screw ships was the danger of the screws getting injured. I must say we have experience at this moment which strongly confirms that, because I have just sent three ships to Japan through the Suez Canal, all of equal draught, and the two single-screw ships went through without the slightest difficulty, while the twin-screw ship knocked her propellers about in a very sad manner. That is a matter, especially with regard to ships likely to be sent to India through the Suez Canal, of the greatest possible importance. My Lord, Mr. Scott Russell pointed out the value of studying the position of the wave of replacement, and placing the screw in proper reference to it. But Mr. Scott Russell stated, as he was sure to state with his knowledge of the facts, that before you can fix your wave of replacement you must fix the speed of your vessel. I cannot understand myself how, for general purposes, you can fix your vessel's speed—at any rate, the speed of a war vessel—because, as you well know, my Lord, we aim in war vessels at a great maximum speed, and the moment we have the ship with a very great maximum speed, we begin to use her, never, or very seldom indeed, resorting to that maximum speed and making use of it. If you are sending a 13-knot vessel round the world you never think of consuming the fuel required for the development of her maximum horse-power, but on the contrary you immediately reduce the consumption of fuel very largely, and send her on her actual service at a speed which has no relation whatever, so to speak, to her maximum speed. Therefore it is important, if we have to fix the position of the screw with relation to the wave of replacement, to know what speed we are to select, whether the 13 knots at the measured mile, which we are seldom required to do in the lifetime of a ship—but which when you wish to get it is of the greatest possible importance—or the average speed which we use in the ordinary service of the vessel. That is a point which I mention because I am satisfied that most of us who heard Mr. Froude's Paper a year or two ago with reference to the position of the wave of replacement and its bearings on forms and proportions of vessels, will connect that valuable Paper with the remarks of Mr. Scott Russell, and will see that the point involved is one of the greatest importance, but the difficulty in applying it is also I think extremely great, because of the varying speed at which ships are impelled. If Mr. Scott Russell could throw some light on that point I should be glad. There is one other remark which I wish to make bearing on these experiments, although I do not think it has any great weight. You will observe on looking at Mr. White's Tables that the differences in the number of revolutions of the engines are not generally enormous, but I believe that our indicated horse-power in all our returns is liable to be in fault in the matter of revolutions. We only time our revolutions in units, and I myself on measured-mile trials have noticed marked discrepancies between the revolutions taken in the engine room and used in the calculations of indicated horse-power afterwards, and the revolutions taken on deck by myself and my officers. Why I mention it is this. If you take a ship developing her full power with a small number of revolutions, and make a difference of 1 revolution, or even 2, as I have known, of the engines, and you add 2 revolutions of the engines, making 50, you add enormously to the indicated horse-power as recorded; whereas if you add 2 with the engines going, as some of the vessel's engines were going—I see 81 in the case of the *Iron Duke*—you do not extract the indicated horse-power in anything like the same proportion. I think that Mr. White has been so careful and so wise in my humble opinion in fencing all his statements with a proper guard that we have not the slightest fault to find with the Paper; but on the other hand if any one should be disposed to make close comparisons between pairs of ships, I think that suggestion is one of considerable importance. I want to make one other remark, and that is

that, for some reason or other—I do not know quite how it happens—we are getting, I think, rather too few of the results of the trials of Her Majesty's ships. It is very ungracious to say that at a moment when Mr. White, an Admiralty officer, has given us these valuable records, but still I think it is the proper moment to mention that circumstance. Many years ago—I think your Lordship was in power at the time—I remember, when quite a private person, asking that we might have the records of the trials of Her Majesty's steamships placed before the Profession and the public, and the whole of them were given to me at that time for publication in the *Mechanic's Magazine*, which I was then associated with. Since that time we have had occasionally in our own *Transactions* and other places the Admiralty records put before us, but I would venture to suggest that we have not had for a long time connected and full reports of the trials of Her Majesty's ships; and while that fact enhances the value of those we do get, yet I think it worth the consideration of this Institution whether we could not ask the Admiralty to give us the results of the trials of Her Majesty's ships a little more freely than they have been doing of late years. Perhaps the only reason is that they have not been asked for them, but if that is so, the fault rests with us. One thing is certain, that if the trials of Her Majesty's ships are made under conditions so free comparatively from the exaggerations which attend the trials of many other vessels, they would be of peculiar value in these days when the Admiralty are building ships of such diversified types and such varying qualities: it would be a very great advantage indeed to naval architects and to marine engineers to have the trials of Her Majesty's ships more fully in their possession.

Sir Robert Spencer Robinson, K.C.B., F.R.S., Admiral (Vice-President): I only rise to supplement what my friend Mr. Reed has said about the non-publication of Admiralty trials. It is in the interests of this Institution, both of the engineers and of the designers of ships, that the fullest publicity should be given to those trials, and he has not at all exaggerated the remarkable reticence of the Admiralty for several years past. When he and I were connected with Admiralty matters, every year, as regularly as the time came round, the whole results of the Admiralty trials during the twelve months were printed and tabulated in the most minute form, giving a vast amount of very valuable information, and besides the official people connected with dockyards and shipbuilding, one hundred or one hundred and fifty copies were distributed amongst those people who had most interest in the subject, and in fact anybody who chose to apply for a copy of those trials received it. Since 1872 no such publication has been made—there has been no calculation accessible to the public, to shipbuilders, or to the makers of engines; and I could not, while listening to the very valuable Paper Mr. White has put before us, considering the extreme interest of the information contained in it, and the scope of the argument which he endeavoured to adduce in favour of twin screws, help feeling that it was a very great misfortune to everyone that the results of the Admiralty trials had not been circulated in the same way as they had been in previous years. If it were not an unkind or an ill-natured thing to say, one almost might have supposed that the non-publication of these trials was with the view of concealing certain unfortunate failures that had taken place, but I believe that no such motives could influence the judgment of the officers of the Admiralty in withholding these valuable results from us. I have several times been asked why the publication of this information has been withheld from us, and the suggestion that I have just hinted at has been made, than which I think nothing more illiberal or ill-natured could have been said. In the interest therefore of those public officers who work so hard and who deserve so much encouragement from society and from every Member of this Institution, I trust that this reticence in publishing important facts which influence the construction of ships and the building and trial of engines will no longer be maintained, and that we shall have the fullest information, as we have had in past years, that the Admiralty can supply.

Mr. James Wright (Vice-President): I should like to say a few words, not with reference to Mr. White's Paper generally, because he has so fully stated the subject both for and against the twin screws, but with reference to the *Iris*, and more particularly with regard to Mr. Reed's remarks. He has characterised the *Iris* as a failure. To a certain extent she is, so far as her speed is concerned.

Mr. E. J. Reed: That is all I said.

Mr. Wright: That failure is not in any measure due to the hull or to the engines. So far as we can see at present, and I think those who have considered her trials will bear me out in saying this, it is due to the screw only—she is very much overscrewed. The two-bladed screw was simply the same screw as the four-bladed one with the two intermediate blades taken off. These experiments were made in connection with Mr. Froude, and it was desired to get the results as nearly under the same conditions as

possible to determine the friction and resistance. If you follow out the lower curve you will see that with 7,000 horse-power she would go about 18 knots, and that is more than was expected, because she was only expected to go between 17 and 17½. With the two-bladed screw, if the blades were strong enough, so that the whole power of the engines could be put out on them, no doubt the full speed expected from the *Iris* would have been obtained. It is only right for me, who was chiefly responsible for the design of the screw, to clear my colleagues from any blame as regards the ship, and as regards the performance of the engines nothing could be better. Improving the screw is a very simple matter, and very easily done. I regret to say I know very little of the conditions under which the twin screws in these very high-powered ships work. I hope to be able to get some experiments made with the *Iris* with the view of getting data for future guidance, and I hope the results of those experiments will be laid before the Institution for the information of the Members. Just one other remark with regard to what Mr. Reed said about the revolutions and the manner in which the engine-power was calculated. I should have thought Mr. Reed would have given us more credit for that than he has done. As a matter of fact the revolutions are taken on the measured mile by two counters. There is one man set to each counter and the revolutions are taken independently. If they do not agree the average of the two is taken. By that means, and by taking the revolutions over the whole run of a mile, I think it must be allowed there is very little chance of error, to even the very small fraction of a revolution. There is one other thing I should like to give an explanation of, and that is Sir Spencer Robinson's remarks about the tables of trials. A number of years ago, when Sir Spencer Robinson was at the Admiralty, an order was given that these trials should be considered as confidential; and as we all know Admiralty traditions are rather lasting sometimes, that order has never been removed, but I have no doubt if the matter were represented in a proper manner there would be no difficulty in getting the order removed, and that the Papers as published would be given as was the case formerly.

Mr. William Denny (Member of Council): I wish to support the request of Mr. Reed, because in the North the wish is often expressed that we should have the results of the Admiralty trials. I must say that I never heard such a suspicion as Sir Spencer Robinson has mentioned that he heard mooted on the subject. The only thing I have heard is, what is my own wish, that the Admiralty, having benefited directly and indirectly the mercantile marine in many ways, might add to that benefit information with regard to all their trials. There is a great deal of this information contained in Mr. Scott Russell's book, but we wish we had it completed. One other remark, and that is with regard to the danger of twin screws being broken. I think Mr. Reed somewhat over-rates that. It is quite true that the Suez Canal is a very crucial place for twin screws, but there is a large amount of water in the world which is not the Suez Canal. On the Clyde twin screws are at present being used for tug boats, and of all uses you would fancy that to be one which would subject them to very great risk; but that risk has been entirely obviated by the breadth of the vessel on the deck being carried to the full extent aft to the stern, so that really the stern overlaps each of the twin screws to the same extent as an ordinary stern would overlap a single screw. I thought it worth while calling attention to this, because difficulties of this kind should not be feared too much if they are really capable of being overcome.

Mr. John R. Ravenhill (Member of Council): I will ask the indulgence of the Meeting for a few minutes, my name having been mentioned in this Paper. First, I should like to remark that Mr. White tells us of the great improvement in the speed of the *Invincible* from shifting the position of the screw in the fore-and-aft line of the vessel.

Mr. W. W. White: And altering the pitch.

Mr. J. R. Ravenhill: Yes, and also altering the pitch. In the case of the *Vanguard*, the sister ship, there was a considerable difference between the vertical centre line of her propellers and the rudder-post; there was a very considerable difference between those lines in the *Iron Duke*, another sister ship, and in the *Vanguard;* and I know, at the time, the Admiralty authorities considered that the increased speed of the *Vanguard* was to some extent to be attributed to it. It would increase the value of Mr. White's Paper, I think, if he could just add a column giving us the relative positions of the screws in the way I describe. As regards the *Arni Illah* and the *Muini Zaffer*, it was a trial made some years back, but very carefully conducted, and there was one very great advantage in that trial as far as comparison went. I am now speaking of the results obtained by the machinery. The boilers were identically the same, and it is to your boilers that you must look for your power. There was a very great difference between the

disc area of the twin screws, in proportion to the midship area of the vessel, and in that of the single screw.* There is also another point connected, I think, with vessels fitted with double screws which nobody has alluded to to-day, and that is this—anybody who sees a vessel in dock must be struck with the fine lines aft that can be continued to the rudder-post, as against the form that the shipbuilders are obliged to adopt to bring them into the stern-post in the case of single screw. I was in hopes that Mr. Scott Russell would have alluded to it when he was addressing us just now, because he could have explained it in a way that I will not attempt to do, but I am sure there is a great deal in it. As far as regards the records of revolutions, I think it only due to say I think few have attended more Admiralty trials than I have, and I am sure the revolutions were always most accurately recorded. In the olden time, when watches were taken out of the pockets and used, somebody would begin one when he ought to have started nought, and in that way got quite wrong; but at the present time the revolutions are to be fully relied on.

Mr. J. A. Thornycroft (Member): I should like to make a few remarks about the *Iris*, and to say that as far as the probable speed of the *Iris* mentioned by Mr. Wright is concerned, I quite concur with him, and consider that the fault in that vessel is due entirely to the screw. It somewhat takes me aback that we are not in possession of information that should enable us to determine the proper size of the propeller, so that it might have been designed at once for the vessel. I now beg to mention Mr. Froude's Paper, to which I attach a great deal of importance, and I think the manner in which this subject has been dealt with offers great promise that we shall now have a method determined by which screws may be designed for vessels so as to fulfil the conditions thoroughly, and give the best results at once. I have made very many experiments with propellers myself, but I feel that now the ground is opened quite differently to me to what it has been previously. As to the angle of maximum efficiency which Mr. Froude mentions, it seems strange that we should find, after so many experiments, that it is a definite angle, whereas it was the previous impression of many people that that angle should be varied to suit a particular vessel. With regard to what has been said about the following wave in vessels, and the propeller being placed on that wave, the fact seems to have been neglected that that wave should follow the vessel. It is not by utilising the motion of that wave and the propeller that the best result has been got, but by using the wave to support and balance the forward wave and its resistance to the vessel. The diagram on the wall showing the speed and horse-power of the *Iris* with the two-bladed propeller, shows very clearly the great speed which is to be anticipated in the *Iris*.

Mr. E. J. Reed: I just wish to remove from the mind of Mr. Wright any idea that I spoke of the failure of the *Iris* as reflecting either on the designer of the ship or of the engines. I thought I took very great pains to avoid doing that; I tried to explain that I referred solely to the result. I wish to say that I quite agree with Mr. Wright in the hope that by adopting the modified plan he proposes, he will obtain the speed that was intended. I tried to avoid casting a reflection upon anybody connected with the construction of the vessel.

The President: Gentlemen, as Sir James Ramsden is not here, Mr. Woolley will give some explanation of this model of a yacht which is upon the table, and which I may say is a very interesting one.

Mr. A. Sedgwick Woolley (Secretary): The model is of a yacht that was built five years ago by Sir James Ramsden, in which the experiment was tried of putting a small screw in front of a larger one. He drives that by a small engine quite separated from the large one, and he finds that when the small screw is driven at twice the number of revolutions of the larger one, he obtains an increase of 2 knots an hour—the difference between 8 knots and 10 knots.

Mr. William Henry White (Member of Council): With reference to the case of the *Iris*, I should like to make a few additional remarks. In the Paper itself I hope the case has been stated better than it was in my hurried *resumé* of the Paper. These are the facts: If the *Iris* had been a single-screw ship, to steam 15¾ knots, with a two-bladed screw such as is fitted in the *Volage*, she would have required over 4,500 horse-power, this estimate being based upon the actual performance of the *Volage* and what we know of the average ratio of effective to indicated horse-power. As a twin-screw ship, with the defective

	Avni Illah.	*Muini Zaffer.*
* Area of immersed midship-section of vessel at measured mile trial in square feet	471·8	405
Total disc area of propeller or propellers in square feet	176·7	226
Proportion midship-section to disc area	2·67	1·79

two-bladed screws (for they are so) which were improvised for the trials, she obtained that speed with less than 4,400 horse-power, which fact seems to show that the twin screws, even working under those disadvantages, with engines developing somewhat more than half their full power, were doing better than a single screw, driven by engines developing their full power, would have done in the same ship. Mr. Wright has dealt with the question of revolutions. I need not say a word about that point. As regards the use of the four blades adopted originally in the *Iris*, I desire to make one other statement. The four blades were adopted there originally because they had done well in other ships, and were known to reduce vibration, and to give a more even action. Even now I think I am right in saying that there is no final decision to use two-bladed screws in the *Iris*. The question is one for experiment, and it may be that three-bladed screws of small diameter and altered pitch would give as excellent results as could be obtained from two-bladed screws. As to the question of diameter, Mr. Thornycroft remarked how little we know about it, and I may add that in the *Iris* the screws were made with an enormous disc area in proportion to their power. There is no doubt we have erred on the side of giving too great an area, but this proportion of disc-area to engine-power has always been done by a sort of rule of thumb. It must be always remembered that in single-screw ships of war there has been a sort of axiom that, with regard to the diameter of the screws, the larger it could be made the better. These facts must be considered in relation to the actual trials and performances of the ship. I do not think I need say anything more about the *Iris*. I will now come to Mr. Merrifield's remarks. I am quite at a loss to follow his objection to my statement. Merchant ships are, I am quite aware, of deeper draught in relation to their breadth, but they are also ships of very different proportions, and having very much less resistance than ships of war. The consequence is, as I have pointed out in the Paper, that merchant ships with twin screws could use very small screws as compared with those we are compelled to use in ships of war, and these small twin screws in deep-draught merchant ships ought, to my thinking, to perform better than the twin screw of proportionately large diameters compared with the draught which are necessarily fitted in our large ships of war. The thing that seemed to me worth looking into in that comparison was this: what would be the amount of shelter for the twin screws in these merchant ships of narrow beam? I took a great deal of trouble, or rather it was taken for me by a friend of mine, to answer this question, and found that in the Atlantic steamers twin screws 13 to 14 feet in diameter could do all the work required. There is surely good reason for some one to make this trial, and to see whether in the deep-draught merchant ships, with these small screws well down, an economy of power is not obtainable; and, especially, I should say that if the efficiency of twin screws for merchant ships is to be tried at all, let it be tried in a vessel on the Australian line, where a break-down in the great stretch across from the Cape to Australia would be a matter of very great importance. There is only one other thing I have to say. Deep draught is a thing which diminishes resistance, and would give the twin screw a good chance in merchant ships. I am extremely obliged for the reception which my Paper has met with, and I hope it may cause further attention to be given to a subject which I think is of very great importance.

Mr. E. Froude: I think, in the absence of the writer of the second Paper, it is not necessary to say anything in reply.

Note.—The following communication was received from Mr. G. B. Rennie (Member of Council) subsequent to the Meetings.—*Ed.*

"To the Secretary,
"Institution of Naval Architects. "London,
"*April*, 1878.

"In Mr. W. H. White's Paper on 'The Comparative Efficiency of Single and Twin Screw Propellers in Deep-draught "'Ships,' read at the April Meeting, it is shown that certain of H.M. Ships (especially the *Alexandria* and *Temeraire*) "require less power to propel them at their deep draught than at their light draught; but he does not seem to assign any "cause for this remarkable fact.* I therefore think it might be interesting to the Institution to have their attention called

* In Mr. White's Paper, page 37, a reference will be found to the effect of deeper immersion in several ships on the performance of the screws.—Ed.

" to certain experiments made by Mr. George Rennie in 1856 (and in which I assisted and witnessed), to ascertain the " pressure exerted by a screw-propeller at different depths of immersion with a constant number of revolutions, and enclose " a copy of the drawing and results of experiments for printing in the *Transactions* of the Institution, from which one " would infer that the cause of the deeper draught ships requiring a smaller proportion of power is due to the greater " efficiency of the propeller when deeper immersed. For example, the resistance of the propeller, as shown in the " experiments, was 49 lbs. when the water just covered the propeller.

" It was increased to about *four* times with 6 inches of water over screw-propeller, and about eight times with 4 feet " 6 inches over the propeller. The propeller's diameter was only 1 foot 9 inches, and of equal pitch, the revolutions being " constant at all depths.

" Taking the area of disc of propeller at 346·3 square inches, these pressures give about—

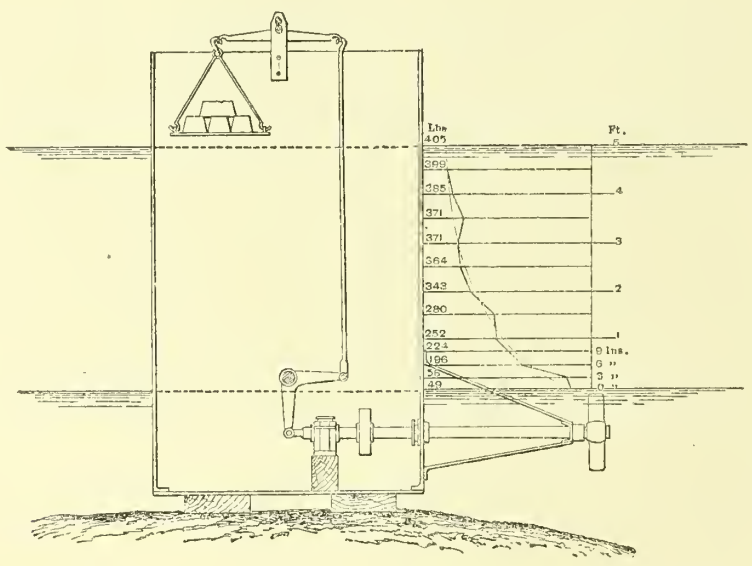
" 7 lbs. per square inch with screw just immersed.
" 28 „ „ 6 inches over propeller.
" 56 „ „ 54 „ „

" *N.B.*—This great extra resistance at the deeper draughts may account for the improved speed obtained in a yacht " (a model of which was exhibited by Sir James Ramsden) by placing a small propeller near the keel.

" The experiments were carried out as follows:—

" (1.) An iron tank (Fig. 1) was placed on the bed of the river in front of our wharf at Blackfriars, a shaft was passed " through a stuffing box on one side of the tank, one end of which carried a screw-propeller of 1 foot 9 inches diameter and

FIG. 1.



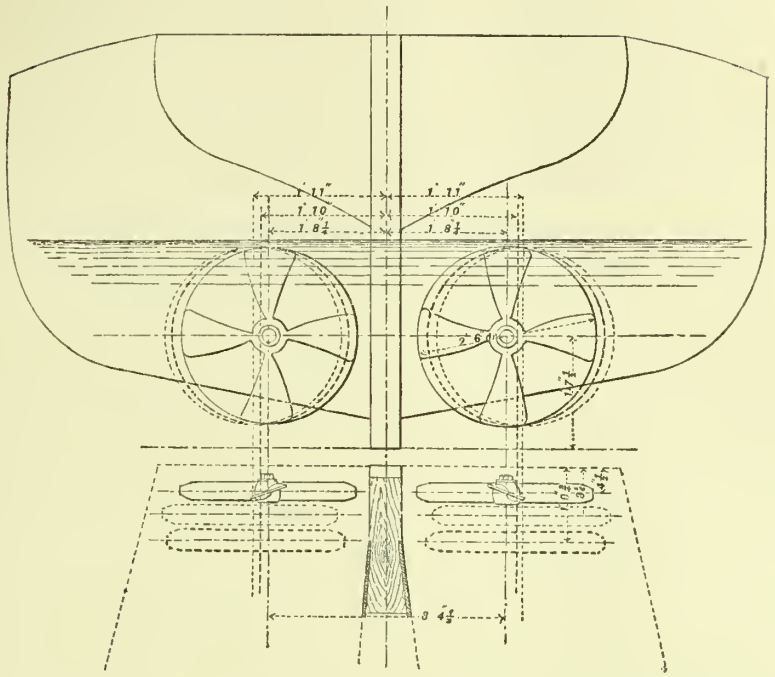
" equal pitch, which worked in the open river. The propeller being of the ordinary two-bladed Admiralty pattern, made of " gun metal and filed up bright to offer little frictional resistance. The other end of the shaft passed into the tank, in " which also was the arrangement for taking the thrust by means of a right-angle lever connected with a balanced " lever. The actual thrust was easily ascertained by means of weights in the balanced scales. A rigger was fixed about " half way between the stuffing box and thrust, from which a leather belt was connected to the factory shafting and engine, " so that a constant speed of 558 revolutions per minute could be maintained at all depths and resistance of propeller.

" (2.) Mr. White calls attention in his Paper to the effect of the position of the screw-propeller. I may mention that " I made certain comparisons of speed and power in some steam launches by placing the propeller nearer the stern-post. " I found, taking the same power of engine, that when the centre of propeller was only—

" 4½ in. forward of stern-post a mean speed of 8·117 knots was obtained.
" 8½ „ „ „ „ 8·003 „ „
" 12½ „ „ „ „ 7·642 „ „

" The Drawing (Fig. 2) shows the relative positions.

FIG. 2.



" Mr. White suggests whether the screw-propellers can be protected. I may mention that I fitted a steam launch of " 36 feet length with a protective casing round the propeller and tried the speed with and without the casing, and it did not " appear to me that the speed was affected by its adoption; but that whereas the propeller 'ran away' or raced with any " slight swell due to a passing steamer, the same propeller when encased was not so affected.

" Mr. R. Griffiths has been making many experiments on a small scale within these last few years, with a view to " ascertain the effect of casing the propeller; but the experiments made by Mr. G. Rennie in 1857 showed that the thrust " of the propeller when working in a conical tube was slightly decreased.

" I am, yours,

" George B. Rennie."

ON THE THEORY OF DEEP-SEA OR OSCILLATING WAVES.

By Joseph Woolley, Esq., LL.D., Vice-President.

[Read at the Nineteenth Session of the Institution of Naval Architects, 11th April, 1878; the Right Hon. Lord Hampton, G.C.B., D.C.L., President, in the Chair.]

The admirable observations of our Vice-President, Mr. John Scott Russell, and the no less admirable synthetical application to them of the principles of hydrodynamics by the late Professor MacQuorn Rankine, and our Vice-President, Mr. Froude, have established the physical constitution and properties of deep-sea waves on so firm a basis, and have, in fact, so completely exhausted the subject that it would seem a hopeless task to attempt to enlarge our knowledge with respect to them.

The synthetical or geometrical process which they employed is, however, by its nature, not exclusive; *i.e.*, while it establishes the fact that deep-sea waves, as observed, do conform to the known laws of fluid motion, it does not exclude the possibility of the existence of other forms. The more powerful method of analysis can alone avail for this purpose. Attempts have been made to apply this process; two of which have come under my own observation—one by Mr. Imray, communicated in the first instance to the Royal Society, and subsequently published in *Naval Science* (*see* 13th number, April, 1875, pp. 231-240); and the other by M. Bertin, also published in *Naval Science* (*see* 7th number, October, 1873, pp. 489-492). Neither of these, however ingenious and instructive they undoubtedly are, seems to the writer entirely satisfactory; the former, inasmuch as it professes to prove, *à priori*, that all the contours of the wave at different depths are necessarily curves of equal pressure by a method involving what seems to be a fallacy (to which I shall recur); and the latter, inasmuch as in the solution of the differential equations to which his method gives rise, arbitrary relations among the constants (involving the depth) are introduced which seem hardly admissible. These are the only two analytical solutions which, as far as I know, have been hitherto attempted, and either of them would have been readily and thankfully accepted by me as complete but for these objections.

The object of this Paper is to give an analytical solution of the problem free from these imperfections; on the one hand, steering clear of the fallacy which I have noted, and on the other, determining the constants on considerations apart from all arbitrary assumptions. It occurred to me that the Members of this Institution might wish to have such a solution put on record among its *Transactions*.

The form and nature of waves which would be produced in a perfect fluid, *i.e.*, frictionless and without viscosity, have been investigated by Sir George Airy and Professor Stokes; but such waves differ in important respects from oscillating waves as observed in the sea, and it is no part of my plan to allude to them. It is well known that there is no rotary motion among the particles of waves produced in a perfect fluid,

while there is such motion among the particles in ocean waves. Friction and viscosity, which play an important part in the production of the latter, under the action of the wind, may be quite sufficient causes for the observed differences between the two classes of waves. This is not a part of the subject, however interesting, which I intend to pursue.

It has been customary to assume (1) that the water, in which oscillating waves are raised, is practically unlimited in all directions, so that the form of the waves is unaffected by the bottom or sides of any containing vessel; and (2) that all particles in a line which in the undisturbed water was horizontal, are, when disturbed, arranged in a curve which is not interpenetrated by those of other lines of particles originally horizontal, above or below it; in other words, that for a given depth the equations of such curve, which we shall call a contour or profile, vary from point to point as functions of the time only; but that we may pass from one contour to another of different depth by introducing the condition that the elements of the curve are functions of the depth. This is expressed analytically by the assumption that if x and y be the horizontal and vertical co-ordinates of any point in a wave, $x = f(h, t)$, and $y = \psi(h, t)$; where f and ψ represent certain functions, and h is a depth which does not vary for a given contour; so that these equations will represent a contour for a given value of h while t varies; and that the equations of a contour for depth, $h + dh$, will be

$$x = f(h + dh, t), \text{ and } y = \psi(h + dh, t).$$

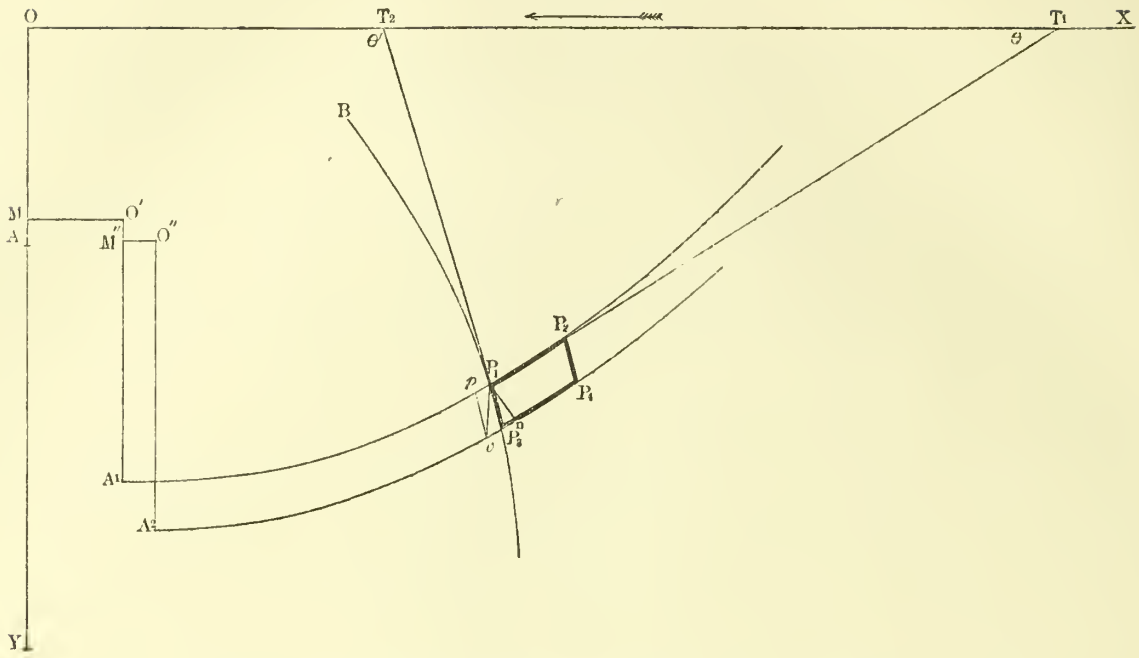
These are all the assumptions made in this Paper. It will, therefore, not be *assumed* that the velocity of transmission of the wave form is the same at all depths; nor that all particles in a line originally (*i.e.* in the undisturbed state) vertical are in the same *phase* of motion (*i.e.* are in corresponding points in the several contours at the same time). In other words, it is not assumed that the wave disturbance reaches particles so placed at the same moment, but may reach those at a lower level before or after it reaches those at a higher level. This implies that $x = f(h, t)$ is of the form $\phi(h) +$ terms in t, which vanish when $t = o$, where $\phi(h) = o$ when $h = o$.

The wave is supposed to travel in a uniform direction, and to be cylindrical in form, so that all sections made by planes parallel to the direction of the wave's motion are similar and equal. Our attention will be confined to the portion of the wave between two such sections where breadth is unity.

The wave crest or hollow travels onward, while each particle describes a certain curve in space. It is convenient to consider the crest or hollow stationary by supposing a velocity communicated to each particle equal and opposite to that due to that of transmission of the wave; this will not affect the relative motion, *i.e.* the wave form.

Let O X horizontal and O Y vertical through the wave hollow be axes to which any point of the wave P_1 is referred; O being an origin having a relation to the upper surface or contour to be hereafter determined; and O X being positive in a direction opposite to that of the wave motion, which is indicated by the arrow; the particle to which O has reference is supposed to be in O Y when $t = o$. Let O′ be the point corresponding to O for the contour $A_1 P_1 P_2 \ldots$; and let O M $= h$ and M O′ ($\parallel$ to O X) $= \phi(h)$. Let the co-ordinates of P_1 in $A_1 P_1 P_2$ be x and y; $A_1 P_1$ being described in time t and $A_1 P_1 P_2$ in time $t + dt$. Then ultimately neglecting small quantities of an order higher than the first, the co-ordinates of P_2 are

$$x + \frac{dx}{dt} dt \text{ and } y + \frac{dy}{dt} dt$$



And if $A_1 P_1 = s$, then $A P_1 P_2 = s + \frac{ds}{dt} dt$ and $P_1 P_2 = \frac{ds}{dt} dt$.

Let $A_2 P_3 P_1 =$ be the contour corresponding to depth $h + dh$: so that $M'' O'' = \phi'(h)\, dh$ ult^{y}; and let $B_1 P_1 P_3$ be the curve joining all the particles in successive contours for which t is the same, *i.e.* in the same phase. Then ult^{y} the co-ordinates of P_3 are $x + \frac{dx}{dh} dh, y + \frac{dy}{dh} dh$; and $A_2 P_3 P_4$ being the arc described in time $t + dt$, the co-ordinates of P_4 are

$$x + \frac{dx}{dt} dt + \frac{dx}{dh} dh, \text{ and } y + \frac{dy}{dt} dt + \frac{dy}{dh} dh.$$

Hence $P_1 P_2 P_3 P_4$ is ultimately a parallelogram, and $P_1 P_2$, $P_1 P_3$ are small portions of the tangents at P_1 to $A_1 P_1 P_2$, $B_1 P_1 P_3$. Let $B_1 P_1 = s'$ then $B_1 P_1 P_3 = s' + \frac{ds'}{dh} dh$ ult^{y}. Let θ and θ' be the angles which tangents at P_1 to $A_1 P_1$ and $B_1 P_1$ make with O X respectively

$$\text{Then } \tan\theta = \frac{\frac{dy}{dt}}{\frac{dx}{dt}} \text{ and } \tan\theta' = \frac{\frac{dy}{dh}}{\frac{dx}{dh}}$$

$$\text{And } \cos\theta = \frac{\frac{dx}{dt}}{\frac{ds}{dt}}, \ \sin\theta = \frac{\frac{dt}{ds}}{\frac{dt}{ds}}; \ \cos\theta' = \frac{\frac{dx}{dh}}{\frac{ds'}{dh}} \text{ and } \sin\theta' = \frac{\frac{dy}{dh}}{\frac{ds'}{dh}}.$$

$$\text{And area } P_1 P_4 = P_1 P_2 \times P_1 P_3 \sin(\theta' - \theta) = \frac{ds}{dt} dt \times \frac{ds'}{dh} dh \,(\sin\theta' \cos\theta - \cos\theta' \sin\theta)$$

$$= \left(\frac{dx}{dt}\frac{dy}{dh} - \frac{dy}{dt}\frac{dx}{dh}\right) dt \,.\, dh \qquad . \quad . \quad . \qquad (1.)$$

Now the condition of continuity of the fluid (*i.e.*, that the small area enclosed between four contiguous points remain the same throughout the motion) requires that the quantity within the brackets on the right-hand side of this equation be independent of t (although it may be a function of h) call it A.

$$\text{Then A} = \frac{dx}{dt}\frac{dy}{dh} - \frac{dy}{dt}\frac{dx}{dh} \quad . \quad . \quad . \quad . \quad (2.)$$

Let P be the pressure at P_1, then $P + \frac{dP}{dt}dt$, $P + \frac{dP}{dh}dh$, and $P + \frac{dP}{dt}dt + \frac{dP}{dh}dh$ are the pressures at P_2, P_3 and P_4 respectively. Also $\frac{d^2x}{dt^2}$ and $\frac{d^2y}{dt^2}$ are the accelerations of P, and if ρ be the density of water, $\rho\frac{d^2x}{dt^2}$ and $\rho\frac{d^2y}{dt^2}$ are the moving forces and forces equal and opposite to these must with ρg, where g is the acceleration of gravity, satisfy the equation of fluid equilibrium, or

$$\frac{dP}{dt}dt + \frac{dP}{dh}dh = -\rho\frac{d^2x}{dt^2}\left(\frac{dx}{dt}dt + \frac{dx}{dh}dh\right) + \rho\left(g - \frac{d^2y}{dt^2}\right)\left(\frac{dy}{dt}dt + \frac{dy}{dt}dh.\right)$$

And since h and t are independent variables

$$\frac{1}{\rho}\frac{dP}{dt} = -\frac{d^2x}{dt^2}\frac{dx}{dt} + \left(g - \frac{d^2y}{dt^2}\right)\frac{dy}{dt} \quad . \quad . \quad . \quad . \quad (3.)$$

$$\frac{1}{\rho}\frac{dP}{dh} = -\frac{d^2x}{dt^2}\frac{dx}{dh} + \left(g - \frac{d^2y}{dt^2}\right)\frac{dy}{dh} \quad . \quad . \quad . \quad . \quad (4.)$$

Now *assume* that $A_1 P_1 P_2$ is a curve of equal pressure, or that all along this curve $\frac{dP}{dt} = o$. Then (3) gives

$$-\frac{d^2x}{dt^2}\frac{dx}{dt} + \left(g - \frac{d^2y}{dt^2}\right)\frac{dy}{dt} = o \quad . \quad . \quad . \quad . \quad (5.)$$

Now $-\rho\frac{d^2x}{dt^2}$ and $\rho\left(g - \frac{d^2y}{dt^2}\right)$ are the resolved parts of the whole resultant force acting on P_1. Let ϕ be the angle which this force makes with O X, and let ρ F be the force. Then

$$-\rho\frac{d^2x}{dt^2} = \rho\,\text{F}\cos\phi \text{ and } \rho\left(g - \frac{d^2y}{dt^2}\right) = \rho\,\text{F}\sin\phi$$

$$\text{And } \frac{\frac{dy}{dt}}{\frac{dx}{dt}} = \tan\theta$$

hence (5) becomes

$$1 + \tan\phi\tan\theta = o \quad . \quad . \quad . \quad . \quad . \quad (6.)$$

Or the force ρ F is at all points at right angles to $A_1 P_1 P_2$

And $$\rho\,\text{F} = \rho\,\text{F}\cos^2\phi + \rho\,\text{F}\sin^2\phi = -\rho\frac{d^2x}{dt^2}\cos\phi + \rho\left(g - \frac{d^2y}{dt^2}\right)\sin\phi$$

But from (6) since

$$\tan\theta = \frac{\frac{dy}{dt}}{\frac{dx}{dt}}$$

$$\cos\phi = -\frac{\frac{dy}{dt}}{\frac{ds}{dt}} \text{ and } \sin\phi = \frac{\frac{dx}{dt}}{\frac{ds}{dt}}$$

$$\therefore \rho F = \left\{ \rho \frac{d^2x}{dt^2}\frac{dy}{dt} + \rho\left(g - \frac{d^2y}{dt^2}\right)\frac{dx}{dt} \right\} \frac{1}{\frac{ds}{dt}}$$

or introducing the value of $g - \frac{d^2y}{dt^2}$ given by (5), and remembering that

$$\left(\frac{dy}{dt}\right)^2 + \left(\frac{dx}{dt}\right)^2 = \left(\frac{ds}{dt}\right)^2$$

we have

$$\rho F = \rho \frac{d^2x}{dt^2} \frac{\frac{ds}{dt}}{\frac{dy}{dt}}$$

Draw $P_1 n$ perpendicular on $P_3 P_4$ and call it p, then

$$p = P_1 P_3 \sin(\theta' - \theta) = \frac{ds'}{dh} dh \sin(\theta' - \theta)$$

but

$$A\, dh\, dt = \frac{ds}{dt} \cdot \frac{ds'}{dh} \sin(\theta' - \theta)\, dt \cdot dh$$

$$\therefore p = \frac{A\, dh}{\frac{ds}{dt}} \quad . \quad . \quad . \quad . \quad . \quad (6^*)$$

but if $P + dP$ be the pressure at n

$$dP = \rho F p = \rho \frac{\frac{d^2x}{dt^2}}{\frac{dy}{dt}} \frac{ds}{dt} \frac{A\, dh}{\frac{ds}{dt}} = \rho A \frac{\frac{d^2x}{dt^2}}{\frac{dy}{dt}} dh$$

$$\therefore \frac{1}{\rho A} \cdot \frac{dP}{dh} = \frac{\frac{d^2x}{dt^2}}{\frac{dy}{dt}} \quad . \quad . \quad . \quad . \quad . \quad (7.)$$

Hence if a suitable value of A can be found, the pressure of all points of $A_2 P_1 P_3$ differs from that at the corresponding point of $A_1 P_1 P_2$ by $\frac{1}{\rho A}\frac{dP}{dh}$ which must be independent of t or $A_2 P_3 P_4$ is a curve of equal pressure if $A_1 P_1 P_2$ is, which is assumed: As $\frac{1}{\rho A}\frac{dP}{dh}$ is independent of t, since $\frac{dP}{dh}$ and A are functions of h only, we may assume $\frac{1}{\rho A}\frac{dP}{dh} = n$ where n does not contain t but *may* contain h, and equation (7) becomes

$$\frac{d^2x}{t^2} = n\frac{dy}{dt} \quad . \quad . \quad . \quad . \quad . \quad (8.)$$

or integrating once

$$\frac{dx}{dt} = n(y+m) \quad . \quad . \quad . \quad . \quad (9.)$$

where m does not contain t, but from (6)

$$g - \frac{d^2y}{dt^2} = \frac{d^2x}{dt^2} \cdot \frac{\frac{dx}{dt}}{\frac{dy}{dt}} = n\frac{dx}{dt} \quad . \quad . \quad \text{from (8.)}$$

$$= n^2(y+m) \quad . \quad . \quad (10) \text{ from (9.)}$$

or

$$\frac{d^2y}{dt^2} + n^2\left(y - \frac{g}{n^2} + m\right) = o \quad . \quad . \quad (10.)$$

The complete solution of which is

$$y - \frac{g}{n^2} + m = r\cos nt \quad . \quad . \quad . \quad (11.)$$

if $t = o$ when the particle is in O′A_1 (as assumed), and r is independent of t.

The form of this equation shows that y is the same as in a circle radius r and centre at a depth $\frac{g}{n^2} - m$ below O X, let this depth be assumed $= h$.

∴ (11) becomes

$$y = h + r\cos nt \quad . \quad . \quad . \quad . \quad (12.)$$

also

$$\frac{dx}{dt} = n\left(y+m\right) = n\left(\frac{g}{n^2} + r\cos nt\right)$$

$$\therefore x = \phi(h) + \frac{g}{n}t + r\sin nt \quad . \quad . \quad . \quad . \quad (13.)$$

It now remains to find what conditions are requisite in order that A may be independent of t. Substituting the values of $\frac{dx}{dt}, \frac{dx}{dh}, \frac{dy}{dt}, \frac{dy}{dh}$ obtained from (12) and (13) in (2), remembering that n may contain h.

$$A = \left(\frac{g}{n} + nr\cos nt\right)\left(1 + \frac{dr}{dh}\cos nt - r\frac{dn}{dh}\sin nt\right)$$

$$+ nr\sin nt\left(\phi'(h) - \frac{gt}{n^2}\frac{dn}{dh} + r\frac{dn}{dh}\cos nt\right)$$

$$= \frac{g}{n} + nr\frac{dr}{dh} + \left(nr\phi'(h) - \frac{gr}{n}\frac{dn}{dh}\right)\sin nt - \frac{gr}{n}\frac{dn}{dh}t\sin nt$$

$$+ \left(\frac{g}{n}\frac{dr}{dh} + nr\right)\cos nt$$

And that this may be independent of t we must equate to zero separately the co-efficients of $t\sin nt$, $\sin nt$ and $\cos nt$.

hence

$$\frac{dn}{dh} = o \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (14.)$$

or

$n =$ a constant which contains neither h nor t

and is consequently the same for every contour throughout the disturbed water.

also $$\phi'(h) = o$$

$$\therefore \phi(h) = c = o \text{ since } \phi(h) = o \text{ when } h = o \quad . \qquad (15.)$$

and $$\frac{g}{n}\frac{dr}{dh} + nr = o \quad . \quad . \quad . \quad . \quad . \quad . \qquad (16.)$$

or putting $$\frac{g}{n^2} = \mathrm{R}$$

$$\frac{1}{r}\frac{dr}{dh} + \frac{1}{\mathrm{R}} = o \quad . \quad . \quad . \quad . \quad . \quad . \qquad (17.)$$

$$\therefore r = r_0 \epsilon^{-\frac{h}{\mathrm{R}}} \text{ where } r_0 \text{ is the value of } r \text{ at the surface} \qquad (18.)$$

$$\text{And } \mathrm{A} = \frac{g}{n} + n r \frac{dr}{dh}$$

$$= n\left(\frac{g}{n^2} + r\frac{dr}{dh}\right)$$

$$= n\left(\mathrm{R} - \frac{r^2}{\mathrm{R}}\right) \quad . \quad . \quad . \quad \text{from (17.)}$$

$$= \frac{n}{\mathrm{R}}(\mathrm{R}^2 - r^2) \quad . \quad . \quad . \quad . \qquad (20.)$$

Hence when these conditions are satisfied, if $A_1 P_1 P_2$ be a curve of equal pressure, so also is $A_2 P_3 P_4$, and so on by successive induction all the contours below $A_1 P_1 P_2$ are so; but the upper surface being subjected only to the pressure of the atmosphere, is necessarily a curve of equal pressure; hence generally all the contours are so. From the above investigation it appears that O is the centre of the circle described by a particle in the upper surface. Also from (15) all particles originally in the same vertical are at all periods of the motion in the same phase. The equations (13) and (12) now become

$$\left.\begin{aligned} x &= \mathrm{R}nt + r\sin nt \\ y &= h \quad + r\cos nt \end{aligned}\right\} \quad . \quad . \quad . \quad . \qquad (21.)$$

$$\text{Where } r = r_0 \epsilon^{-\frac{h}{\mathrm{R}}}$$

These are the equations to a trochoid, the radius of the rolling circle being R, and that of the describing circle at depth h being $r \left(= r_0 \epsilon^{-\frac{h}{\mathrm{R}}}\right)$

The equations (14) and (21) show that each particle in the wave describes a circle in the same time T′ where $\mathrm{T}' = \frac{2\pi}{n}$ and with uniform angular velocity $= \frac{2\pi}{\mathrm{T}'}$ while the wave advances with a constant velocity $n\,\mathrm{R} = \frac{g}{n}$ which is the same for all contours in the direction of the arrow. If u be this velocity, then

$$u = \frac{g}{n} \text{ or } n = \frac{g}{u} = \frac{\mathrm{T}'g}{2\pi} \quad . \quad . \quad . \quad . \qquad (22.)$$

$$\text{Also } \mathrm{R} = \frac{g}{n^2} = \frac{\mathrm{T}'^2 g}{4\pi^2} \quad . \quad . \quad . \quad . \qquad (23.)$$

Let h' be the depth below O X of the line of particles originally horizontal, which in the motion becomes the trochoid at depth h.

Now since area $P_1 P_4 = A\,dh\,.\,dt$

$$= \frac{n}{R}(R^2 - r^2)\,dh\,dt$$

$$= \frac{2\pi}{T'R}(R^2 - r^2)\,dh\,dt,$$

it appears that the whole area between contours at depths h and $h + dh = \frac{2\pi}{R}(R^2 - r^2)\,dh$ and evidently as much of this lies above the centre O′ as below it, or the mean depth of this area $= h$.

Let $h' + dh'$ be the value of h' when h becomes $h + dh$. Then $2\pi R\,dh' =$ area of fluid between these two successive strata in the undisturbed state which is necessarily equal to the area between the corresponding disturbed strata

$$\therefore\ 2\pi R\,dh' = \frac{2\pi}{R}(R^2 - r^2)\,dh$$

$$\text{Or } dh' = \left(1 - \frac{r^2}{R^2}\right)dh = \left(1 - \frac{r_0^2\,\epsilon^{\frac{-2h}{R}}}{R^2}\right)dh$$

$$\therefore\ dh' - dh = -\frac{r_0^2\,\epsilon^{\frac{-2h}{R}}}{R^2}\,dh$$

$$\text{Or } h' - h = C + \frac{1}{2}\frac{r_0^2}{R}\,\epsilon^{\frac{-2h}{R}}$$

$$= C + \frac{1}{2}\frac{r^2}{R}.$$

To determine C we observe that the smaller r becomes (*i.e.* as the disturbance becomes less) the undisturbed and disturbed line of particles more and more nearly coincide, and ultimately when $r = o$ they absolutely coincide. Hence when $r = o$, $h' - h = o$ and $C = o$. Hence

$$h' - h = \frac{r^2}{2R} \quad . \quad . \quad . \quad . \quad . \quad (24.)$$

This represents the height through which a line of undisturbed particles is raised by the motion at depth h. Let $h = o$ and h'_0 be the corresponding value of h', then

$$h'_0 = \frac{r_0^2}{2R} \quad . \quad . \quad . \quad . \quad . \quad (25.)$$

Taking a slice of the wave of thickness 1 foot, and $w =$ weight of a cubic foot of water, $\frac{2\pi w}{R}(R^2 - r^2)\,dh$ is the weight of an elementary slice, and this is raised through $h' - h$. Hence potential energy of this slice, putting for $h' - h$ its value $\frac{1}{2}\frac{r^2}{R}$,

$$= \frac{2\pi w}{R}(R^2 - r^2)\,dh \times \tfrac{1}{2}\frac{r^2}{R}$$

$$(\text{Or since } dh = -\frac{R\,dr}{r}) = -\frac{\pi w}{R}(R^2 r - r^3)\,dr.$$

Hence for the whole wave integrating from $r = r_0$ to $r = o$, potential energy of the wave

$$= -\frac{\pi w}{R}\int_{r_0}^{0}(R^2 r - r^3)\,dr$$

$$= \frac{\pi w}{4R} r_0^2 (2R^2 - r_0^2) \quad . \quad . \quad . \quad . \quad (26.)$$

Again, since the small area $\frac{2\pi}{T'R}(R^2 - r^2)\,dh\,dt$ is moving with the same velocity (in space) as the point P_1, which is describing a circle radius r with uniform velocity $n r = \frac{2\pi}{T'} r$ the actual energy of this element $= \frac{1}{2}$ vis viva

$$= \frac{w}{2g} \times \frac{2\pi}{T'R}(R^2 - r^2)\,dh\,dt \times \frac{4\pi^2}{T'^2} r^2.$$

Integrating from $t = o$ to $t = T'$ and putting $\frac{T'^2 g}{4\pi^2} = R$, the energy of the whole slice

$$= \frac{\pi w}{R^2}(R^2 - r^2) r^2\,dh$$

$$= -\frac{\pi w}{R}(R^2 r - r^3)\,dr.$$

and whole energy of the wave

$$= -\frac{\pi w}{R}\int_{r_0}^{0}(R^2 r - r^3)\,dr$$

$$= \frac{\pi w}{4R} r_0^2 (2R^2 - r_0^2) \quad . \quad . \quad . \quad . \quad (27.)$$

or the actual energy is the same as the potential energy.

Note.—These three last theorems are not new, but have been introduced because they are obtained by a simple process independently of the properties of a trochoid.

Again

$$\frac{dP}{\rho A\,dh} = n$$

$$\therefore \frac{dP}{dh} = n\rho A = n^2 \rho \frac{R^2 - r^2}{R}$$

$$n^2 = \frac{g}{R} \therefore \frac{dP}{dh} = g\rho\frac{R^2 - r^2}{R^2} = w\left(1 - \frac{r_0^2 \epsilon^{-2h/R}}{R^2}\right)$$

$$\therefore P = C + w\left(h + \tfrac{1}{2}\frac{r_0^2 \epsilon^{-2h/R}}{R}\right) = C + w\left(h + \frac{1}{2}\frac{r^2}{R}\right)$$

when $h = o$, $P = \Pi$ the pressure of the atmosphere, and $r = r_0$. Also observing that $h'_0 = \frac{1}{2}\frac{r_0^2}{R}$ we have

$$\Pi = C + \tfrac{1}{2} w \frac{r_0^2}{R} = C + w h_0'$$

$$\therefore P = \Pi + w \left(h + \tfrac{1}{2}\frac{r^2}{R} - h'_0 \right)$$

$$= \Pi + w (h' - h_0')$$

or the pressure at any point in the wave is the same as in the undisturbed water, which we should have expected.

Mr. Imray seeks to obtain at once the equations of the orbit of the particle.* Thus if x and y are the co-ordinates of a particle and u be the velocity (supposed uniform) of the wave, for $\frac{dx}{dt}$, $\frac{dy}{dh}$ and $\frac{dx}{dh}$ in the solution given above we may put

$$u + \frac{dx}{dt}, 1 + \frac{dy}{dh}, \phi'(h) + \frac{dx}{dh};$$

$\frac{ds}{dt}$ and $\frac{ds'}{dh}$ are the same but their components are $u + \frac{dx}{dt}, \frac{dy}{dt}$; and $\phi'(h) + \frac{dx}{dh}$ and $1 + \frac{dy}{dh}$ respectively. $\frac{dy}{dt}, \frac{d^2y}{dt^2}$ and $\frac{d^2x}{dt^2}$ are the same.

Applying the method already used we get

$$\frac{1}{\rho A}\frac{dP}{dh} = \frac{\frac{d^2x}{dt^2}}{\frac{dy}{dt}} = \frac{g - \frac{d^2y}{dt^2}}{u + \frac{dx}{dt}} \quad . \quad . \quad . \quad . \quad (1.)$$

or since this must be independent of t we must have

$$-\frac{1}{g}\frac{d^2y}{dt^2} = \frac{1}{u}\frac{dx}{dt}$$

$$\text{Or } \frac{d^2y}{dt^2} = -\frac{g}{u}\frac{dx}{dt} \quad . \quad . \quad . \quad . \quad . \quad (2.)$$

and from (1) we get directly

$$\frac{d^2x}{dt^2} = \frac{g}{u}\frac{dy}{dt} \quad . \quad . \quad . \quad . \quad . \quad (3.)$$

integrating each of these once we get

$$\frac{dy}{dt} = -\frac{g}{u}(x - a) \quad . \quad . \quad . \quad . \quad . \quad (4.)$$

$$\frac{dx}{dt} = \frac{g}{u}(y - b) \quad . \quad . \quad . \quad . \quad . \quad (5.)$$

whence

$$(y - b)\frac{dy}{dt} + (x - a)\frac{dx}{dt} = o$$

$$\therefore (y - b)^2 + (x - a)^2 = r^2 \quad . \quad . \quad . \quad . \quad (6.)$$

the equation to a circle radius r and co-ordinates of the centre a and b. The generality of the solution is not diminished by taking the centre as origin or $a = o$ and $b = o$.

* The methods employed by me are not Mr. Imray's, but are equivalent to them, and lead to the same results.

$$\therefore x^2 + y^2 = r^2 \quad . \quad . \quad . \quad . \quad . \quad (7.)$$

Let $y = r\cos\theta$

Then $x = r\sin\theta$

and putting $a = o$ and $b = o$ in (4) and (5), and substituting for $\frac{dy}{dt}$ its value $-r\sin\theta\frac{d\theta}{dt}$ and for $\frac{dx}{dt}$ its value $r\cos\theta\frac{d\theta}{dt}$, we get from either of them $\frac{d\theta}{dt} = \frac{g}{v}$, and the rest of the solution is easily obtained.

Equations equivalent to those of Mr. Imray between $\frac{dP}{dh}$ and $\frac{dP}{dt}$ (see *Naval Science*, No. XIII., p. 234) are obtained by eliminating successively, $g - \frac{d^2y}{dt^2}$ and $\frac{d^2x}{dt^2}$ between equations (3) and (4). Remembering that $A = \frac{dx}{dt}\frac{dy}{dh} - \frac{dy}{dt}\frac{dx}{dh}$ we thus get

$$-\frac{d^2x}{dt^2} = \frac{1}{\rho A}\frac{dP}{dt}\frac{dy}{dh} - \frac{1}{\rho A}\frac{dP}{dh}\frac{dy}{dt} \quad . \quad . \quad . \quad (8.)$$

$$\text{And } g - \frac{d^2y}{dt^2} = \frac{1}{\rho A}\frac{dP}{dh}\frac{dx}{dt} - \frac{1}{\rho A}\frac{dP}{dt}\frac{dx}{dh} \quad . \quad . \quad . \quad (9.)$$

Mr. Imray attempts to obtain another equation as follows:—Drawing $P_1 v$ vertical to meet $P_3 P_4$ in v, and observing that $\rho\left(g - \frac{d^2y}{dt^2}\right)$ is the only force acting vertically downwards, we must have, if δP be the increase of pressure at v over that at P_1,

$$\delta P = \left(g - \frac{d^2y}{dt^2}\right) P_1 v.$$

Now

$$P_1 v = P_1 n \,\text{Sec}\, v P_1 n = \frac{A\,dh}{\frac{ds}{dt}}\,\text{Sec}\,\theta = \frac{A\,dh}{\frac{ds}{dt}\cos\theta} = \frac{A\,dh}{\frac{dx}{dt}}$$

whence

$$\delta P = \rho\left(g - \frac{d^2y}{dt^2}\right)\frac{A\,dh}{\frac{dx}{dt}}$$

and putting $\delta P = dP$

$$g - \frac{d^2y}{dt^2} = \frac{1}{\rho A}\frac{dP}{dh}\frac{dx}{dt} \quad . \quad . \quad . \quad . \quad (10.)$$

Comparing this with (9) he finds that $\frac{dP}{dt} = o$ whence he concludes that the pressure along any wave profile is constant.

The fallacy here lies in considering δP to contain h only. In fact if we draw $v\,p$ parallel to $P_3 P_1$ meeting $A_1 P_1 P_2$ in p, $p\,v$ will be a portion of a curve like $P_1 P_3$ in which the time is constant. Hence to pass to the pressure at v by making h alone vary, we must start from the pressure at p; now this evidently corresponds to a time $t - \delta t$ where

$$\delta t = dt\frac{P_1 p}{P_1 P_2} = dt\frac{P_3 v}{P_1 P_2}$$

$$\text{But } P_3 v = P_1 P_3\frac{\sin v P_1 P_3}{\sin P_1 v P_3} = \frac{ds'}{dh}.dh\frac{\cos\theta'}{\cos\theta}$$

$$\text{And } P_1 P_2 = \frac{ds}{dt} dt$$

$$\text{Hence } \delta t = dt \times \frac{\frac{dx}{dh} \cdot dh}{\frac{ds}{dt} dt \cos\theta} = \frac{\frac{dx}{dh}}{\frac{dx}{dt}} dh$$

$$\text{Hence pressure at } p = P - \frac{dP}{dt} \delta t = P - \frac{dP}{dt} \frac{\frac{dx}{dh}}{\frac{dx}{dt}} dh$$

And instead of $\frac{dP}{dh}$ in (10) we must put

$$\frac{dP}{dh} - \frac{dP}{dt} \frac{\frac{dx}{dh}}{\frac{dx}{dt}}$$

And (10) becomes

$$g - \frac{d^2 y}{dt^2} = \frac{1}{\rho A} \left(\frac{dP}{dh} - \frac{dP}{dt} \frac{\frac{dx}{dh}}{\frac{dx}{dt}} \right) \frac{dx}{dt}$$

$$= \frac{1}{\rho A} \frac{dP}{dh} \frac{dx}{dt} - \frac{1}{\rho A} \frac{dP}{dt} \frac{dx}{dh}$$

which is the same as equation (9). We can therefore get no new equation by mere manipulation of the forces

$$-\rho \frac{d^2 x}{dt} \text{ and } \rho \left(g - \frac{d^2 y}{dt^2} \right)$$

Note 1.

It has been thought unnecessary to prove the formula

$$\frac{dP}{dt} dt + \frac{dP}{dh} dh = \rho \left\{ -\frac{d^2 x}{dt^2} \left(\frac{dx}{dt} dt + \frac{dx}{dh} dh \right) + \left(g - \frac{d^2 y}{dt^2} \right) \left(\frac{dy}{dt} dt + \frac{dy}{dh} dh \right) \right\}$$

For those who are not familiar with it we subjoin an outline proof. Join $P_1 P_4$ and let $P_1 P_4 = dS$. Let α be the angle which $P_1 P_4$ produced makes with O X. Then putting

$$\frac{dx}{dt} dt + \frac{dx}{dh} dh = dx, \text{ and } \frac{dy}{dt} dt + \frac{dy}{dh} dh = dy$$

The co-ordinates of P_4 are $x + dx$ and $y + dy$, and evidently $\cos\alpha = \frac{dx}{dS}, \sin\alpha = \frac{dy}{dS}$. Consider a small prism of the fluid, the axis of which is $P_1 P_4$ and section k; then pressure on end $P_1 = P k$, and on end $P_4 = \left(P + \frac{dP}{dt} dt + \frac{dP}{dh} dh \right) k$; and pressure on end P_4 − pressure on end $P_1 = \left(\frac{dP}{dt} dt + \frac{dP}{dh} dh \right) k$; and this must balance forces equal and opposite to the moving forces on $P_1 P_4$; the corresponding acceleration on $P_1 P_4$

$$= -\frac{d^2 x}{dt^2} \cos\alpha + \left(g - \frac{d^2 y}{dt^2} \right) \sin\alpha = -\frac{d^2 x}{dt^2} \frac{dx}{dS} + \left(g - \frac{d^2 y}{dt^2} \right) \frac{dy}{dS}$$

and the mass of the prism $= \rho k \, P_1 P_4 = \rho k \, d S$. Hence moving force

$$= \rho k \, d S \left\{ - \frac{d^2 x}{d t^2} \frac{d x}{d S} + \left(g - \frac{d^2 y}{d t^2} \right) \frac{d y}{d S} \right\} = \rho k \left\{ - \frac{d^2 x}{d t^2} d x + \left(g - \frac{d^2 y}{d t^2} \right) d y \right\}.$$

Hence equating this to the difference of pressure on the ends, and dividing by k, and replacing $d x$ and $d y$ by their full values, we have

$$\frac{d P}{d t} d t + \frac{d P}{d h} d h = \rho \left\{ - \frac{d^2 x}{d t^2} \left(\frac{d x}{d t} d t + \frac{d x}{d h} d h \right) + \left(g - \frac{d^2 y}{d t^2} \right) \left(\frac{d y}{d t} d t + \frac{d y}{d h} d h \right) \right\}$$

We might by an analogous process obtain the formulæ for $\frac{d P}{d t}$ and $\frac{d P}{d h}$ separately by considering small prisms with axes $P_1 P_2$ and $P_1 P_3$ respectively, since along $A P_1 P_2$ the variation of P depends only on t and along $B P_1 P_3$ only on h, and these lines make angles θ and $90° - \theta$, and θ' and $90° - \theta'$ respectively with the resolved accelerations $- \frac{d^2 x}{d t^2}$ and $g - \frac{d^2 y}{d t^2}$.

Note 2.

A solution of the problem equally satisfactory may be obtained as follows:—

The equation to the tangent to the curve $A_1 P_1 P_2 \ldots$ at P_1 is

$$(Y - y) \frac{d x}{d t} - (X - x) \frac{d y}{d t} = o \quad . \quad . \quad . \quad (1.)$$

where x and y are the co-ordinates of the point P_1. We may obtain from this the equation to the tangent to $A_2 P_3 P_4$ at P_3, by substituting in it the co-ordinates of the point P_3 for those of P_1—*i.e.*, neglecting small quantities of an order higher than the first, by putting $x + \frac{d x}{d h} d h$, and $y + \frac{d y}{d h} d h$, for x and y respectively. We thus get

$$\left(Y - y - \frac{d y}{d h} d h \right) \left(\frac{d x}{d t} + \frac{d^2 x}{d t \, d h} d h \right) - \left(X - x - \frac{d x}{d h} d h \right) \left(\frac{d y}{d t} + \frac{d^2 y}{d t \, d h} d h \right) = o$$

or

$$(Y - y) \left(\frac{d x}{d t} + \frac{d^2 x}{d t \, d h} d h \right) - (X - x) \left(\frac{d y}{d t} + \frac{d^2 y}{d t \, d h} d h \right) - \left(\frac{d x}{d t} \frac{d y}{d h} - \frac{d y}{d t} \frac{d x}{d h} \right) d h = o$$

Also since $d h$ may be made as small as we please, and vanishes in the limit in comparison with unity, the second terms in the co-efficients of $Y - y$ and $X - x$ may be neglected in comparison with the first, and the equation becomes

$$(Y - y) \frac{d x}{d t} - (X - x) \frac{d y}{d t} - \left(\frac{d x}{d t} \frac{d y}{d h} - \frac{d y}{d t} \frac{d x}{d h} \right) d h = o \quad . \quad . \quad (2.)$$

Hence these two tangents are parallel; and if ϕ be the angle which a perpendicular on either of them makes with O X, we have

$$\operatorname{Tan} \phi = - \frac{\frac{d x}{d t}}{\frac{d y}{d t}}, \quad \cos \phi = - \frac{\frac{d y}{d t}}{\frac{d s}{d t}}, \quad \sin \phi = \frac{\frac{d x}{d t}}{\frac{d s}{d t}}.$$

and (1) and (2) may be written

$$(Y - y)\sin\phi + (X - x)\cos\phi = o,$$

$$\text{and } (Y - y)\sin\phi + (X - x)\cos\phi - \left(\frac{dx}{dt}\cdot\frac{dy}{dh} - \frac{dy}{dt}\cdot\frac{dx}{dh}\right)\cdot\frac{dh}{\frac{ds}{dt}}$$

and the difference of the lengths of the perpendiculars let fall from O on these two tangents

$$= \left(\frac{dx}{dt}\frac{dy}{dh} - \frac{dy}{dt}\cdot\frac{dx}{dh}\right)\frac{dh}{\frac{ds}{dt}}$$

but this difference evidently $= P_1 n$ (*see* Diagram) $= p$,

$$\text{or } p = \left(\frac{dx}{dt}\frac{dy}{dh} - \frac{dy}{dt}\frac{dx}{dh}\right)\frac{dh}{\frac{ds}{dt}} \quad . \quad . \quad (3.)$$

but area of elementary parallelogram $P_1 P_4$.

$$= p\frac{ds}{dt}dt = \left(\frac{dx}{dt}\frac{dy}{dh} - \frac{dy}{dt}\frac{dx}{dh}\right)dh\,.\,dt \quad . \quad . \quad . \quad (4.)$$

Hence, as before

$$A = \frac{dx}{dt}\frac{dy}{dh} - \frac{dy}{dt}\frac{dx}{dh} \quad . \quad . \quad . \quad (5.)$$

$$\text{and } p = \frac{A\,.\,dh}{\frac{ds}{dt}} \quad . \quad . \quad . \quad . \quad . \quad (6.)$$

The remainder of the solution is the same as in the text.

DISCUSSION.

Mr. William Henry White (Member of Council): If I may be allowed, as one of his old pupils, to speak of Dr. Woolley's work without presumption, I would observe that having read this Paper and knowing something of other writings on the subject to which Dr. Woolley has referred, I consider his treatment of the subject is far more general than anything I have read before in English or in Foreign publications. I am sure his Paper will form a very valuable addition to our *Transactions*, which contain in the Volume for 1862 the writings of Mr. Froude, and in later years the Papers of Professor Rankine on the same subject. Dr. Woolley's treatment is certainly more general than anything which has gone before.

The President: I must thank you, Mr. White, for having made those observations, which I think are only due to Dr. Woolley. I can only thank him for the information he has given us, which I am sure will be found in our *Transactions*.

ON LIGHTENED SCANTLINGS.

By W. Denny, Esq., Member of Council.

[Read at the Nineteenth Session of the Institution of Naval Architects, 11th April, 1878 ; the Right Hon. Lord Hampton, G.C.B., D.C.L., President, in the Chair.]

Last year, in a Paper read before this Institution at Glasgow, I pointed out certain objections to Lloyd's numerals, and suggested the substitution for them of a series of numerals based upon the displacement, modified by the length and by the dimensions of the midship-section. Some objections were advanced against this suggestion, which might then have been answered, had the time at the disposal of the Meeting not been so limited as to curtail all the Discussions. On this account I have decided, among other matters connected with the subject of this Paper, to take up such objections in as far as they were stated or suggested.

To begin with, there seemed to be an impression that displacement numerals would proceed on some *à priori* principle which would thicken the plating of a large steamer beyond all reason, and thin the plating of a small steamer beyond all safety. As, however, they would be in categories like the present numerals, and as their being so arranged would easily permit limits to be placed to their action, time need not be wasted on this mistake. Any one can very easily see that if the present numerals increased thickness of plating in direct proportion to their increase, or diminished it in a similar ratio of decrease, they would produce as extraordinary thicknesses and thinnesses as any displacement numerals could do, used in the same manner. One of the objections actually put forward to a displacement basis was that it might be a fictitious basis. This may mean that an owner might for the purpose of getting heavier scantlings put the displacement mark at a point he never intended to load to. If he did this he would do no harm. If the objection meant, however, that an owner would attempt to load to such a draught in spite of its being plainly stated in the certificate of class that the mark represented simply a draught not to be exceeded, and in no sense a rule for loading, such an owner might be safely left to the care of the authorities at the port he intended to sail from, who would very quickly enlighten his clever obtuseness. There is one sense in which the displacement basis might be fairly termed fictitious, and that is with regard to the different draughts of the same steamer. In these it is not as a rule the fully-loaded condition which is the worst, but that in which the coal has been consumed. No set of empirical numerals attempts to cover the individual peculiarities of ships, and as the relationship of the greatest strain may be fairly and reasonably assumed to bear a common ratio to the greatest displacements, this objection need not trouble us. It arises from a comparison of the displacement basis with the determination of scantlings by a complete and careful consideration of an individual ship and her special requirements, and has no connection with the point in dispute,

which is the relative value of a purely dimensional and a mixed dimensional and displacement basis. The displacement basis, no more than any other empirical basis, can stand comparison with an absolute consideration of scantlings, ship by ship. Such a method is, of course, the best, but it would mean the negation of Registration Societies. Another objection to the displacement basis is that an owner having built his vessel to scantlings corresponding to a given draught, might desire, on account of a wish to sell the ship, or to change her trade, to load more deeply. In what, however, would he in this, to him, unsatisfactory position, differ from the owner of an awning-decked vessel marked officially for her draught, and who desired to load more deeply? Indeed, from some remarks made at our last Meeting it would seem that the owner of a spar-decked vessel must be assumed to occupy the same position. But it is breaking a butterfly to extend the confutation of an argument which, fully developed, means nothing less than a wholesale condemnation of specialised instruments—an argument which would lead directly up to the proposition that every steamer should be made to do every kind of work in case a future necessity should arise. No one asks an owner to build specialities. All we ask is that under fair conditions and guarantees he should have the liberty of doing so. If he uses his liberty foolishly and to his own hurt he has himself to blame.

Another objection to a displacement basis—a little uncomplimentary to owners—is that they know nothing about displacement. My experience does not confirm this; but granting the statement, may we not assume that even the dullest owner knows the meaning of deadweight capacity, and that this knowledge will enable him to understand fairly well any contract he may desire to make for a ship? The necessity of understanding displacement, and of working out different conflicting elements in connection with it, might be then safely left to the shipbuilder; for competition would in the long run sharpen his wits, even if they were originally blunt, to a very fine appreciation of the problems he had in hand.

It seems universally admitted that scantlings of different degrees of heaviness may be used in the same form and dimensions of ship. We have a general recognition of this in practice, and in the registries. It would be a salient feature in numerals formed on a displacement basis, and therefore specially requires consideration in connection with them. As it is prudent in any investigation of this kind to start from some tangible system already in existence, I have taken the liberty of drawing upon Lloyd's Rules for illustrations, and these are given in the three sections in Plate III., representing the scantlings of a steamer of the same dimensions, form and class, built to the three different grades permitted by the Rules. A Table at the end of this Paper gives the various particulars in connection with the sections. Last year objection was taken to my having assumed the same draught for a three-decked and a spar-decked vessel. I regret that I should have given cause for objection in this; and to show my willingness to meet any such objections fairly and frankly, I have in the present case not only assumed different draughts for the three different grades, but have done so in accordance with Mr. Martell's suggested rules for freeboard.

The displacements corresponding to the different draughts are simply those of the same form, differently immersed. The bending moments are the products of Mr. John's well-known formula, and the moments of inertia and position of the neutral axis are found in the usual way. A consideration of the scantlings of the three different sections shows, taking the transverse construction first, that the frames which are

$5\frac{1}{2}$ inches × $3\frac{1}{2}$ × 9-16ths in the three-decked section become $5\frac{1}{2}$ inches × $3\frac{1}{2}$ × 8-16ths in the spar-decked, and 5 inches × $3\frac{1}{2}$ × 8-16ths in the awning-decked section. The reverse frames are reduced from 4 inches × $3\frac{1}{2}$ × 8-16ths to $3\frac{1}{2}$ × $3\frac{1}{2}$ × 8-16ths, and the floors from 26 inches × 10-16ths to $25\frac{1}{2}$ × 10-16ths, and $24\frac{1}{2}$ inches × 10-16ths. We have thus a steady reduction throughout the transverse scantlings; and we may safely assume that the cause of this is the condition or conditions which have changed in the spar-decked from the three-decked, and in the awning-decked from the spar-decked vessels. But as there is no condition changed saving that of the displacement, we may assume that it is in harmony with its decrease that the transverse scantlings diminish. In considering the longitudinal scantlings you will be struck by the fact that with the exception of 1-16th on every second strake of plating, and some slight reduction in the keelsons, all the reductions are made, and with some decision, above the main deck. To suppose that action of this kind was taken without due reason would be most unjust to the framers of the Rules. The reason fortunately lies to our hands, and can be seen in the strains shown to come upon the uppermost deck of each section, according to Mr. John's formula. These strains are well within the limits of safety, but are principally worthy of remark because they are practically equal, and they are so because the strength of the section tested in this way varies coincidently with the bending moment produced by the formula. As, however, in the formula the only variable is the displacement, it is simpler to say that the strength of each of these sections to resist rupture on its uppermost deck varies as the displacement.

As you may suppose, I should be the very last to blame Lloyd's for proceeding on a displacement basis in lightening scantlings, and I trust that any remarks I am compelled to make adverse to the arrangements of these sections will not be interpreted in such a sense. Indeed, I regret that finding allies I cannot wholly approve their action; for while I am at one with Lloyd's in the opinion that, in the same form and dimensions of ships, scantlings should, down to safe limits, follow the displacement—and they, I am sure, would not any more than myself go further—I am unable to agree with them in the relative reductions they make between the transverse and longitudinal scantlings. So much has of late years been spoken and written about longitudinal scantlings and their importance, and by no one better than by Mr. John, that there has been some little temptation to neglect transverse strength. Lloyd's have to some extent drifted into this error. In deprecating the overworship of longitudinal scantlings do not, however, misunderstand me; for while I condemn the mistakes of those who have of late, and most foolishly, striven simply to get iron placed lengthwise in a ship, I sincerely admire the efforts of those gentlemen, Mr. Scott Russell and Mr. Brunel, who produced a true theory of longitudinal strengthening as exemplified in the construction of the *Great Eastern;* and to this day I think the massing of her transverse strengthening, and its distribution to the skin by means of longitudinals, a pattern and model of skill worthy of careful study. The Admiralty constructors to a large extent, and with some necessary modifications, following the same course, have shown what wonders of strength and lightness can be produced by it. Few words are, however, required to distinguish the spurious systems of longitudinal construction produced of late from the true, and to condemn them as they deserve. I do not of course charge Lloyd's with encouraging these spurious systems, although, as the illustrations in Plate III. clearly show, the Rules undervalue the transverse framing. Taking the scantlings of our three sections below the main deck you will notice that going

from the three to the awning-decked section the reductions in sectional area amount to about $4\frac{1}{2}$ per cent. on the skin, 16 per cent. on the frames, 7 per cent. on the reverse frames, and 5 per cent. on the floors. There is a very marked difference apparent here between the reduction so freely undertaken on the framing, and that so timidly attempted on the skin. The cause of this anomaly is not the requirements of the longitudinal strengthening, for they could have been left really unaffected, even if a fair reduction had been made in the skin, providing some of it had been added to the stringer and sheer strake of the uppermost deck. The requirements for local strengthening can hardly be the cause, for the plating is fairly above them. One interpretation is available, and it is, that having as a matter of choice reduced the framing, the thickness of the plating was left to succour it. If this is correct the choice is to be regretted, and is tolerably clear evidence of the small importance attached to the transverse framing in the mercantile marine. One is almost tempted to believe that the consciousness of having resisted any attempt to widen the frame spacing has lulled the general opinion into a quiet confidence in the framing as it is, and induced the notion that if one only has close frames and thick plating all else will come of itself.

Mr. White pointed out last year that one of the functions of the skin was to contribute to the transverse strength. The remark is valuable, and is well illustrated by the Admiralty system of construction. For the purpose of more plainly showing its force, and the relationship of the framing to the plating in this duty, I have had three skin sections prepared and calculated in a way suggested by Mr. Reed in his book on "Shipbuilding in Iron and Steel." They represent strips of plating cut the breadth of a frame spacing from between the bilge and the stringer above it, in the awning-decked and three-decked section; and to these is added a similar section from Her Majesty's ship *Blonde*. The sheathing of the *Blonde* is omitted as it would only complicate the comparison. The omission does not however affect the value of the illustration afforded by the section. We can now try which of these three sections, for the material in it, would contribute most to the rigidity of a ship's side. To take the very simplest illustration of this, we may suppose that each of these sections is subjected to the kind of strain so frequently experienced in docking at Liverpool—a strain tending to push the side in and to produce rupture in the inner flange of the reverse frame. The moment of inertia has been calculated for each section, also the distance of the inner flange of the reverse frame from the neutral axis. We may assume the power of this inner flange to resist the strain brought to bear on it to represent the relative rigidity of the sides, and that the moment of inertia of each of the sections divided by the distance of the inner flange of the reverse frame from the neutral axis represents this power of resistance. Tried in this way the rigidity of the three sections is represented relatively thus:—

Blonde class	30·6
Three-decked grade	18·7
Awning ditto	15·38

The areas of iron in the three sections are, the

Blonde class	33·5 square inches
Three-decked grade	24·806 ditto
Awning ditto	23·75 ditto

Comparing the three-decked and awning-decked sections, we have in the latter a reduction of about 4 per cent. of sectional area, producing a reduction in rigidity of nearly 18 per cent. Comparing the *Blonde* section with the awning-decked section we have an increase of 41 per cent. of sectional area producing nearly 100 per cent. more rigidity, and this barely represents the gain; for by throwing the rivet holes close in to the skin in the *Blonde* section the reverse frame is made more effective against tensile strains than in either the three-decked or awning-decked sections. What we have however markedly to note is, that by reducing the scantlings of the awning-decked as compared with the three-decked section principally, in the framing, we have for a total reduction of 4 per cent. of scantlings reduced the power of the side to resist any strain forcing it in, at points unsupported save by the frame and reverse frame, 18 per cent. This seems an undesirable result, and not one which would encourage any person to persevere with a further application of a displacement basis. You must however acknowledge that it is no necessary feature of the displacement basis policy, but rather the result of indifference to the requirements of the transverse strengthening. What a fruitful source of trouble this indifference has been, experience shows. We hear too frequently of large ocean steamers breaking in frames in docking, and we hear as frequently of the most clumsy remedies for the evil, a thicker skin or closer spacing of the frames. I know one large and important ocean company which for this reason have reduced the spacing of their frames from 24 to 21 inches with the result of only very slightly remedying this weakness, largely increasing the weight of the structure, and as Mr. White clearly pointed out in his Paper on the "Relation of Frame Space and Shift "of Butts to the Butt Fastenings of the Skin Plating of Iron Ships," very considerably reducing the tensile strength of the skin. There can also be little doubt but that a very large amount of the skin weakness observed in ocean steamers, about and above the bilges, is due to the want of rigidity in the internal framing. The continual thickening of the skin at this part seems a strange remedy, for in most mercantile steamers the bilge is so square that it is excellently fitted to resist compression, while it is almost always far stronger against tensional strains than the upper works, and far less exposed to them. We are indeed compelled to acknowledge that a large amount of the skin weakness observed in the mercantile marine is due to the skin not being properly and rigidly supported, and not to defects in itself. The continual additions of sixteenths to its thickness or an adherence to that thickness, while the internal framing is being considerably reduced, are not real remedies. It is not of course meant by this that we are to seek in a copy of the *Blonde* section a remedy for these mistakes, but only that we should, subject to our own requirements, adopt the line of action indicated in it. There are many and good reasons why we cannot in mercantile ships afford the very wide frame spacing of the Navy, and why we must have more frequent support.

There is, however, nothing to prevent us remedying our present defects by simply, in cases of lightened scantlings, dividing the reduction more fairly between the skin and framing, preserving the depth of the framing and being particularly slow to reduce the reverse frame. A little more attention might also be afforded to the beam knees, of which one tier at least should be made large and effective. The deeper framing would of course afford them better fastening and enable them to prevent racking in the section. Surely what I now recommend is no novel, no revolutionary and dangerous procedure, but a prudent course of action worthy of the attention both of Lloyd's and all mercantile constructors. The lesson of it is taught in the admirable

systems of construction developed by the Admiralty, systems which are worthy of the careful study of every one desiring to master the practice of construction, and specially worthy of attention at this time when the mild steel now coming into use puts directly before us the question of how a general reduction is to be prudently conducted. If the disregard of the transverse framing we have been discussing is carried into steel construction, it can safely be predicted that we shall shortly hear of skin weaknesses in steel ships.

Although the changes in framing now recommended would be improvements on the present system, they would be, by no means, all that could be done; and if I take up some little of your time in sketching out a line of progress, I trust you will excuse me, for lightened scantlings are not only a feature of the construction of the same dimensions and form of ship with different displacements, as we see illustrated by Lloyd's practice, but are also a feature in the improvement of construction itself, and the full scope of their application cannot be described without a few words about this feature. Reference has already been made to the massing and distribution of the transverse strengthening of the *Great Eastern*, so admirably practised by Mr. Brunel and Mr. Scott Russell. There is, however, more than this worthy of notice in their system of construction, and what strikes me most is, that having to provide a certain amount of area of section for meeting tensile and compressive strains they made it do double work. Herein lies the beauty of the true longitudinal method of construction. Leaving the outer skin comparatively thin they left it workable to advantage. In forming an inner skin and connecting the two by longitudinals, they produced a mass of box girders which distributed the transverse strength of the thwartship bulkheads to the hull. At the same time all this longitudinal strengthening fulfilled its ordinary functions in resisting the great longitudinal strains of tension and compression. Nothing can be more ingenious than this arrangement by which the transverse bulkheads are drawn upon for transverse strengthening and compelled to do more than merely sub-divide the hull. Throughout the whole construction you have material forced to do two duties, and sometimes three and four. Mr. White illustrated a similar practice in the Admiralty, where portions of the structures of the iron-clads intended for defence were made to contribute to the strengthening of the whole structure. It is, perhaps, worth while in connection with this to note the waste of the strength stored up in the transverse water-tight bulkheads of mercantile steamers. These reservoirs of transverse strengthening are not only wasted, but dreaded, and, instead of supplying rigidity to the hull have to be prevented from damaging it by bulkhead doublings of a size far beyond what is required, simply for the purpose of compensating the close pitch of the bulkhead frame rivets. Surely in the face of all we know, of the teachings of Mr. Scott Russell and Mr. Brunel, and of the practice of the Admiralty, this is a poor result. To what does it point? It points to the fact that we shall not improve in mercantile construction till we learn to mass our transverse strengthening and distribute it. Then our transverse water-tight bulkheads will be simply more pronounced examples of a general feature in the construction, and will need no such special treatment as we supply at present in unnecessarily large bulkhead doublings. To attain this end we need not make mere copies of the *Great Eastern's* construction, although I believe for the largest ocean steamers something of the kind would be the lightest and strongest construction. Framing can be and is frequently massed without employing a cellular construction. Massed framing means of course partial bulkheads, or what are commonly called bracket

frames. Lloyd's have taken a step in the right direction in applying them in the machinery spaces of steamers where they make good the want of beams. A dread of destroying stowage capacity has prevented them carrying the method further and reaping the full benefit from it. This dread is, however, exaggerated, for although it is quite true that these partial bulkheads projecting into the holds break stowage, it must be apparent that in many cases by doing away with hold stringers of great width, or hold beams and stringers, they would increase, instead of diminishing stowage, while even in cases of diminution of stowage, if the scantlings longitudinally depended upon a displacement basis rather than upon the dimensions of the midship-section an owner could nearly recoup his loss by enlarging the sectional dimensions of his ship. This is an illustration of one way in which Lloyd's longitudinal numerals may be found to impede improvements in transverse strengthening. On the advantages of massed transverse strengthening and the opportunity it would afford stringers and keelsons of distributing its effect to the whole hull while fulfilling at the same time longitudinal functions it is unnecessary to dilate. Such a construction would afford the fullest opportunity for lightening scantlings down to local requirements, and for obtaining strength and rigidity by a multiplication of many moderately thick parts, rather than by the thickening of a few parts fulfilling only single functions. We may, besides, remark that with hand riveting, which is practically universal in shipbuilding, it is undesirable to greatly increase the thickness of parts, as the whole advantage of doing so is never gained. It is rather prudent to have many thin parts than a few thick ones, seeing that for the area of section involved, square inch for square inch, the former is likely to be the more reliable. Should the use of mild steel increase for shipbuilding, additional force will be given to these views by the greatly increased deterioration in thick as compared with thin plates, caused by the punching. We have abundant scope before us for improvement, but we have plenty of light to guide us, in the history of construction up to date and in the Admiralty practice, if we are willing to learn from them.

	Awning Deck.	Spar Deck.	Three Deck.
Length	320′ 0″	320′ 0″	320′ 0″
Breadth	40′ 0″	40′ 0″	40′ 0″
Depth	33′ 11″	33′ 11″	33′ 11″
Draught moulded	19′ 1″	21′ 2″	23′ 4″
Displacement	4,224	4,869	5.512
Co-efficient of displacement	·605	·629	·646
Area of midship-section	661	748	835
Lloyd's frame numeral	81·25	88·5	96·35
Lloyd's plating numeral	25,837	28,063	30,639
Upper deck from neutral axis	20·68	19·93	19·35
Moment of inertia	168,438	189,538	200,025
Bending moment $= D \times \frac{L}{35}$	38,607	44,502	50,379
Strain on upper deck	4·74	4·68	4·87

DISCUSSION.

Mr. Benjamin Martell (Member of Council): My Lord, I think this Paper is of too much importance to be allowed to pass without a few remarks, therefore I will take the opportunity of making a few. I think we are greatly indebted to Mr. Denny for devoting his attention to the requirements of very large ships, and ships of extreme length in proportion to their depth and breadth. No doubt the system of longitudinal framing described by Mr. Denny is a very excellent system indeed—we all admit that; we have all given credit to Mr. Scott Russell for it in this Hall over and over again. I do not want to compliment him any more, but all I can say is that we highly approve of it. At the same time I think it would have been better if Mr. Denny had drawn a line of some kind to show where this system of longitudinal framing is especially required. It is not required in the great bulk of mercantile steamers. If we were to introduce a system of longitudinal framing for the transverse framing which we have at this time, I am quite certain that no builder throughout the country would follow it for ordinary vessels. When you get to huge vessels such as the *Great Eastern*, it is a system of construction highly to be approved of. But even if we were to adopt it in the larger class of merchant vessels, of 300 feet in length and above, it would be much objected to, and is objected to by a very large class of owners. I know from my own experience that they have objected to it, because they say the internal capacity of vessels, whatever Mr. Denny may think as to its not doing so, is reduced very much by these web frames in comparison with the stringer plates. I assure him the general impression is that the loss is very serious indeed in ordinary stowage, and the principle of construction, therefore, is not generally accepted by shipowners. If a shipowner however wanted to build a ship of that kind, and liked to submit such a ship to Lloyd's Committee of Registration, Lloyd's Committee would be very pleased to accept such a ship for classification, and I think I am permitted to say in this Hall that they would give her the highest class in their Registry provided they saw that her strength was equal to the requirements of their Rules; but it would be a folly for us to introduce such a system into our Rules, because with the great bulk of ships such a system is not required. Now, with reference to the displacement basis it seems to me really, with all due deference to Mr. Denny, that we should be by adopting such a system only introducing a new set of empirical numbers for the numbers that Lloyd's Registry have in force now. I can see no difference whatever. All the main objections raised to this at Glasgow, you will allow me to say with great respect to Mr. Denny, have not been replied to, and still exist; and I could, if I had time, raise an objection to every point—what I said on that occasion, and many more objections have occurred to me since. Therefore I really cannot see that any purpose would be answered by substituting another set of numbers for the numbers which Lloyd's have at this time. With reference to the comparison which has been made here with these sections, I am sorry I have not had the opportunity of going more thoroughly into them, and I had to say the same thing on one other occasion, because I think they are altogether wrong.

Mr. William Denny (Member of Council): I do not think you will find them wrong.

Mr. B. Martell: I assure you they appear to me to be so, and I ought to know the Rules of Lloyd's Registry Society. I will give you now one instance. I assure you that the arrangement of those two vessels, the awning-deck ship and the spar-deck ship, appear to me to be perfectly wrong in a most essential point. In the first place the framing of one ship is made different from the other, whereas they should be both alike. That is one thing that occurs to me at once. If you were to adopt your longitudinal system, although it is much stronger generally for the whole ship; it is very much weaker locally if you are going to put your great deep frames a greater distance apart, and unless you could ensure in docking the ship that the shores would be put opposite those deep frames, you would find very much greater danger of their breaking up like eggshells.

Mr. Denny: I did not say your ships.

Mr. Martell: No. We know that the Admiralty have to take very great care in shoring their ships when they have these very deep web frames to put the shores against them. If you had the vessel in an ordinary dock where they dock ships you could not tell from the outside the position of these deep web frames, and if they put the shores between these frames, having merely a shell plating or light frame in between, there would be far more danger of this outside plating breaking than there

would be in the ordinary system of construction, where you have continuous strength direct from end to end of the ship. At the same time I agree with you that if we adopt that system we shall have to a considerable extent to modify the system of construction. I have very great pleasure in saying, from what I know, and from what you have submitted to me privately, that your ideas flow with mine to a very great extent, and with others likewise on the Clyde who have done the same thing. I have great pleasure indeed in saying so. One of the gentlemen I see here now submitted a scheme which seems to me to be most desirable in that direction; and if we work together in that direction I am sure progress will be made, because it is the desire of the Committee of Lloyd's Register to do all that they can to forward progress in shipbuilding—not to lay down their Rules, although rules for iron ships, as iron rules, but to modify them in any way where an intelligent shipbuilder can show he can produce a good structure equal to the strength required by their Rules. If he can do that, Lloyd's Committee will give her the highest class in their Registry. I cannot see for myself that there is any very great difficulty arising, and I hope that we shall meet each other in this spirit and work together for the good of the Mercantile Marine.

Mr. G. Thompson: In answer to Mr. Denny, I would say that I understood him to mean that he wanted transverse sections, and not longitudinal sections. Mr. Martell has had a model before him of longitudinal frames for his examination, and to bring it before the Committee so that I might know if they would give the highest character to any ships so built; this model has never been brought before Lloyd's, although I do not know the reason why. As regards the longitudinal strength of ships, I passed a ship a week ago in the South West India Dock; I could count every butt in midships, and if she is not in dry dock now, any gentleman can do the same. The ship is one of the highest class in Lloyd's, and I believe a well-found ship. This proves to me that the longitudinal strength of iron ships is not up to its mark, or what it ought to be, and I hope that the advisers of Lloyd's Committee will be very careful how they recommend light construction in the way that they are doing, because in my opinion in innocence they have made some very serious mistakes from the year 1862 to 1872, by reducing the scantlings, which have been the cause of loss of many fine ships. If they had stuck to their old Rules of 1862 they would have stamped the Liverpool Book out. With regard to docking, I have docked a great many ships, but never saw a shore go through once, but I have seen a bran-new vessel classed at Lloyd's, and I can give you the ship's name if you like, come into the East India Dock with a fender as big as my body between the side and the ship, and still it goes through the ship and breaks three frames. Is that what a ship ought to be? And yet you want lighter construction. Then there is steel, which Mr. Martell brought forward this morning. I consider that to be a very serious danger in shipbuilding. I believe it is almost impossible for you to get the same quality right through one plate. My experience is that very often in the same plate you would find great differences in quality, and that you could not shear it or punch it at one end the same way as you could at the other. As regards steel rivets and so on, I think that by Lloyd's Rules riveting is overdone entirely. In all my experience—I will say in almost all cases—the rivet stands when the plate is worn away. That shows you overdo the riveting. I should say that conical-headed rivets were the best, although they are the most difficult to repair.

Mr. John Scott Russell, F.R.S. (Vice-President): I have, my Lord, but one single observation to make upon the point put by Mr. Martell in regard to mercantile ships. Some friends of mine and I made, long before the *Great Eastern* was built, certain mercantile vessels entirely with longitudinals, and we did so entirely on mercantile principles, looking to the great room for stowage which they gave us. I do not think it is generally known to those who have not made use of the longitudinal structure of ships, that the stowage between those longitudinals allows the stowage to go to the very skin of the ship. If you want a wooden lining fixed on the skin of the ship, instead of sacrificing room you gain room, because your frames are not there, and therefore in every one of those large divisions you can stow cargo, and we did stow cargo; and I beg to say that something like twenty of the most money-making ships that ever went out from the River Thames made their money by the enormous stowage they had in between those longitudinals. Now, if that is so, I can only congratulate Mr. Denny on the attitude Mr. Martell has taken. Lloyd's refused to class these ships for six or eight years until they found out that other people wanted them who did not mind their classification, and then they very kindly came forward and classed them. Now I hope Mr. Martell, while he is in power, will profit by this excellent exposition of Mr. Denny. I think it ought to be remembered that Mr. Denny represents to a certain

extent the Clyde men, and I think it ought to be remembered that the Clyde men hate the longitudinal system, and as a rule have persevered in the frame system, in putting larger weight into it than anybody else almost up to the present time—that at least is my impression; perhaps I am wrong. Therefore you may be quite sure that Mr. Denny has not said a word in favour of the longitudinal system which was not actually required by the qualities which the longitudinal system itself possesses. I promise, therefore, to Lloyd's, that if they will make favourable Rules for the longitudinal system of vessels, and for shipowners who may happen to have some of them, although they know nothing about the mechanical structure of the ships—if they will show them by favourable Rules that they can make a ship to have this grand stowage we have been talking of, and the great strength which Mr. Denny says they have, without fining them, as they are now fined, for building a weaker vessel than they do the other way, I have no doubt that the owners will end by being very grateful to Mr. Martell, and very grateful to Mr. Denny, for having introduced them to a very much stronger, a very much more durable, and a very much safer structure of ship, with a larger stowage for goods between the longitudinal frames.

Mr. John Corry (Associate): As a Member of Lloyd's Committee, I can quite bear out what Mr. Martell has said, and can promise on behalf of the Committee, that if any such system as Mr. Denny has pointed out for the longitudinal construction of large ships were brought before them, it would receive their favourable attention. They are quite aware of the great value of longitudinal framing, but they also know that it is only in very large structures that it becomes a necessity. The ordinary transverse framing which is usually employed is cheaper and simpler for general purposes. That is all I have to say on that point. With regard to the statement made by Mr. Scott Russell, I was rather astonished that a gentleman of his experience should advocate stowage against the skin of a ship. I am a shipowner, and to all those who understand the stowage of a vessel, of course such a system appears absolutely ridiculous as applied to ordinary cargoes. It may do for coals, or something very rough indeed. I do not know where we should be if we put our cargoes against the skins of our ships. As shipowners we would have very heavy claims to pay, and we have heavy enough claims now as it is. It requires a great deal of trouble to guard against sweating and condensation, and we have to take every possible means to get rid of their bad effects by keeping our cargoes well free from the skin of the ship.

Mr. J. Scott Russell: I would merely mention this, that a large quantity of the cargo was of a kind that admitted of it—wine casks and matters of that description, which suffered no inconvenience from coming in contact with the skin. Where that was not the case we also scarcely sacrificed anything by lining each of these compartments with its own lining of wood. Therefore it is not at all essential, nor has it anything to do with the longitudinal system, that you should either line it or not line it. It is equally capable of being lined or not lined; and, as a shipowner well knows, it depends entirely on the nature of the cargo whether you would have more cargo and less lining, or more lining and less cargo.

Mr. William John (Member of Council): My Lord, I should like to offer one or two observations on Mr. Denny's Paper, and in the first place in regard to this question of the displacement basis. I should like it to be clearly understood how the matter stands. If my memory is right, at Glasgow, Mr. Denny proposed that the scantlings should be based on a formula which involved the displacement multiplied by the length and a fraction; and, as I understood him at that time, the scantlings of the vessel were to be made proportional to this formula, which was to represent the breaking strain of the vessel. At that time I think it was pointed out that you cannot embody in a formula all the various scantlings of a ship, or even lay down any formula to which the scantlings of a ship will be proportional; therefore, what we argued was that a displacement basis such as Mr. Denny's would only replace numerals like Lloyd's present numerals in this way:—you have to represent a certain sized ship by a certain number, whether numerals such as ours, or whether they represent a displacement. You must have a certain upper and lower limit, because you cannot, as I have explained I think, go up by such small gradations of plating that you can have a perfectly mathematical series. You must go within certain practicable limits of size. What I say is this:—That our numerals represent fairly, roughly, certain sizes between the upper and lower number—they represent fairly a certain sized ship, and if you had the upper and the lower displacement you would still have a margin between those two which you would not get over by a displacement basis any more than you would by a tonnage or a numerical basis such as we have. I see that Mr. Denny has entirely departed, if I understand his view rightly, from making or intending to make the scantlings proportional to his numerals, whatever they may be. He says when you have your

displacement or your numeral you have to put your scantling and your size of frame opposite to them, and if you go up from 100 tons to 1,000 it does not follow that you will multiply by 10 all your scantlings. I quite agree with that. I do not pretend that we do it now. What we do is this. We get numbers which fairly represent the sizes of the ships. The sizes put against those numbers in the Table were not determined from any formula, they are the result of experience more than anything else, and Mr. Denny, when he has got his numbers, admits that the numbers do not give him the scantlings to place opposite the numbers, and I should like Mr. Denny to explain to us the connection between the numbers and the scantlings placed opposite to them. That is where the real difficulty of forming any Table of Scantlings lies.

Mr. W. Denny: I will with much pleasure explain that in my reply, if I have time.

Mr. W. John: Another point which I will draw attention to is those three sections (Plate III.) I quite endorse what Mr. Martell said about those sections. Those frames, it appears to me, cannot be correct. Now, about those three sections and the comparison made with the *Blonde*, I should like to say this—the ships are entirely different ships. You have here, in the Government ship *Blonde*, frames 10 inches deep, and those frames are spaced 3 feet 6 inches apart, and you want in that ship very strong framing and very great rigidity, because those ships have to carry heavy guns and to resist the concussion of those guns. But you see how the particular type of the ship makes, as it were, facilities for carrying out the structure. You are able to put in that ship frames 10 inches deep, and 3 feet 6 inches apart, because you cover them with 6 inches of wood, and you in that way have the local support for the plating which you would not otherwise have. I do not believe for a moment that if the *Blonde* had been designed to be an iron ship, without a wood sheathing outside, that those scantlings or those arrangements of framing would have been applied. Then there comes another point in connection with them. It is the easiest thing in the world to take a certain part of a ship and to apply a formula to it and bring out a certain result. But it does not at all follow that that result is anything that you can be much guided by. I should like to ask Mr. Denny, as he gives the figures for the *Blonde* and those two ships, and he takes a frame space, whether he is taking 3 feet 6 inches of length of the *Blonde* to compare with 2 feet of length in the other ships?

Mr. W. Denny: I have taken 48 inches. In that case that decreases the rigidity of the sides as compared with the 3 feet 6 inches.

Mr. W. John: In the other ships you took the 2 feet?

Mr. W. Denny: Yes.

Mr. John: If you take the 2 feet the figures do not represent the comparative transverse strength of those ships, but a strength taking 2 feet length of the merchant ships and 48 inches or 4 feet of the other ships. I say you can go as far as you like in that way. Take the *Blonde*, and instead of having the frames 10 inches make them 12 inches and space the frames 6 feet apart. If you put it through the same formula you get far greater results, and yet you get a worse structure. Now in reference to the general principle of construction, I think Mr. Denny is perhaps misrepresented in one respect. I do not think he is advocating entirely a longitudinal system, but what he is advocating, if I understand him rightly, is what he calls massing transverse strength. We all know that if you have two 3-inch angle irons side by side you cannot get the same strength out of them which you can if you put one inside the other and get nearly 6 inches deep; but in carrying out the construction of a ship you have not only to think of that, but you have to think of the support of the plating and other things. I grant that it might be a better ship if you could make, say, every alternate frame bigger than the others, and have a large frame, and then an intermediate small frame. If you could do that you would have a better structure most likely with the same material, but you would have a lot of difficulties in the way of carrying longitudinal stringers, angle irons, and various things of that kind which we have to think of, and besides you would have more broken stowage, as Mr. Martell has very properly said; and, on the whole, we have to give up our particular fancies as to what would scientifically make the best structure, owing to the necessities of the case, because when you come to work it out and to face the difficulties which there are, you are driven to give up your crotchets and to carry out more practical ideas. I quite agree with Mr. Denny, that a good deal might be done in the way of having transverse web frames at certain distances apart, and having the strength from those transverse frames transmitted over the vessel by means of longitudinals. We quite agree with that, and we are always delighted to see any section coming up in which this question of internal space and stowage is sacrificed to a structural arrangement of this kind. I hope

that the Meeting and Mr. Denny will not think for a moment that we stick to Lloyd's Rules from any pet theories, or from any fancy that they are perfect so far as structural strength is concerned. We know they are not. They conform as far as possible to the exigencies of the case. Not only has Mr. Denny submitted proposals to us for web-frames of this kind, but we have had somewhat similar proposals from other builders on the North-East Coast, one, two, and three years ago, and we have always been most happy to take as favourable a view of them as we possibly could.

Mr. W. Denny: Regarding the criticisms passed on my Paper I would, first of all, express the pleasure I feel at the courteous way in which Lloyd's have met me, and the willingness expressed by them to meet anything coming from outside: I hope they will continue in this frame of mind. Mr. Martell has told you that my sections are wrong: I have, however, no hesitation in saying that they are right, and if I had Lloyd's Book with me, which I am sorry I have not, there would be no difficulty in showing you proof for my assertion. Last year, Mr. Martell in criticising the three sections then produced mistook the deepest one for a three-decked section, on account of its having three tiers of beams—the Rules requiring hold beams to be introduced when the depth exceeded a given amount. These mistakes only show that the Rules are a little difficult to understand. In these three sections I have to point out the following facts to you:—The Rules lay down distinctly that in the three-decked section the tranverse scantlings are to be fixed by the three-decked numeral, that is, the full depth added to the full breadth and half girth, minus seven. For the spar-decked section the Rules lay down that the transverse scantlings are to be fixed by the two-decked Rule up to the main deck, and in the awning-decked section it is distinctly laid down in the Rules, and as clearly as possible, that the transverse scantlings are to be fixed by the two-decked Rule or the three-decked Rule to the main deck. That implies that in the awning-decked case I am at liberty to take the depth, half girth and half breadth to the main deck, and to deduct seven from it. If you take roughly the depth between decks at seven feet, this means that off the addition of the full depth of the section, full half girth and half breadth, you will have for the three-decked section seven deducted, for the spar-decked section twice seven, and for the awning-decked section three times seven. This is a clear explanation of the point in dispute, and any one here can verify it for himself. I have taken care to come before you advisedly in speaking of this matter. I am sorry to differ from Mr. Martell, who is a personal friend of my own, but where printed documents are in question I appeal to them, and I trust you will verify them for yourselves. If I am found wrong there are opportunities in the public prints of contradicting me. In another point Mr. Martell, however kindly disposed, has rather mistaken my aims. There are two things in this Paper—one is a prospective sketch of possible improvements in construction, the other is my recommendation to Lloyd's of a method of putting themselves right on the framing question, which is, that they should preserve the depth of the frames and keep the strength in the reverse frame, whatever they do. They have not met this question in any other way than by disputing the correctness of the awning-decked section. But even supposing it were wrong, nobody doubts the reality of the difference between the three-decked and spar-decked section, and that involves the same question upon only a less scale. I have advised means of putting this matter right, and I believe Lloyd's will put it right. In this there are no theories involved, no longitudinal construction, but simply a counsel given by Mr. Reed in his book, *On Shipbuilding in Iron and Steel*, which has lain neglected. We shipbuilders owe Mr. Reed our thanks for his book. With regard to the bracket frame or deep-plate frame system, Mr. John said in his Paper last year that these partial bulkheads would never do, because they destroy stowage. We are at present building four steamers of 2,000 tons, and these ships we had arranged to Lloyd's Rules with hold beams every 24 feet, and a deep hold stringer. We submitted in lieu of this to Lloyd's a section with plate frames 12 inches deep. You must not, however, think they projected 12 inches into the hold, because, deducting 8 inches from them for the depth of the ordinary frames (which is 6 inches), and the thickness of sparring (which was 2 inches), the plate frames only came 4 inches into the hold. I have had the loss of stowage calculated for a hold 96 feet long. With Lloyd's ordinary construction it would have been 760 cubic feet, but with the deep plate frame construction it was only 40 cubic feet. I am quite willing this should be verified, and have no wish that what I am bringing before you should be misunderstood. I believe if you are to get proper stowage and right construction combined, you will only get it with partial bulkheads, and I am quite certain that Mr. John himself will be one of the first to acknowledge a scientific necessity, and in the matter of science I bow to him. Now another question. Mr. John has said that in the displacement basis, which I brought forward last year, I meant to follow theoretically the numerals which would be formed

by this displacement basis. I really said nothing of the kind; but that there must be categories in any numerals, because numerals are empirical, and categories are characteristic of empiricism. Lloyd's numerals were, I believe, formed on the basis that a ship was taken of the smallest midship-section consistent with the displacement in a given number of depths and breadths, that the midship-section was covered with scantlings having the necessary moment of *inertia* to be strong enough for that section, and that these were called the base scantlings. Those would be sufficient for this largest possible displacement on a given length with the smallest possible midship-section, and the ship would be strong enough. According to my displacement basis, I should start in the same way; but if the midship-section were blown out to twice the size, I would not reduce the longitudinal scantlings, as Mr. John has said, to a minimum, but keep them the same, thereby perhaps doing a possible injustice; but what injustice compared with Lloyd's unnecessarily increasing these scantlings as it was blown out? The fact is, Gentlemen, Lloyd's numerals will sooner or later have to be changed or modified, and if they are not, you will see improved numerals in some other Society, the Bureau Veritas or the Liverpool Underwriters. It is quite impossible for Lloyd's to stand still. The numerals are wrong, whatever Mr. John or Mr. Martell may say, and I am prepared to meet and discuss them further with them at any time they please. I have to thank you, my Lord and Gentlemen, very much for your attention.

Mr. E. J. Reed, C.B., F.R.S., M.P. (Vice-President): One word on a point of order. I have noticed in one or two speeches this evening a tendency in the speakers to address themselves not to the Chair, but to the Meeting a great deal too much and to the Chair a great deal too little. The Discussion has been rather warm and a little too personal, and I would venture to suggest that our Meetings should not be allowed to degenerate into a personal conversation, and that if the Members of the Institution would address the Chair a little more carefully we should be likely to avoid any deterioration in the character of our debates. I confess that I am a little afraid if we do not do that we shall have some slight tendency to personality growing up in the Meetings.

The President: As Mr. Reed has appealed to the Chair on a point of order of course it becomes my duty to notice the remarks which he has made, and I am bound to say that I think Mr. Reed is quite right, and that it is far better in Discussions of this kind at such a Meeting as this that every speaker should address the Chair. I do not know that I agree equally with Mr. Reed with regard to the reason which he has assigned, which was that the Discussions were becoming rather warm, because I may say for my own part I am glad of it. I like to hear a little spirit, because it only shows the zeal of the speakers, and how earnestly we enter into these important national questions. However, I cannot hesitate for one moment to say that it is desirable speakers should address the Chair and not the Meeting generally.

ON THE LOAD LINE OF STEAMERS.

By John Wigham Richardson, Esq., Member.

[Read at the Nineteenth Session of the Institution of Naval Architects, 11th April, 1878; the Right Hon. Lord Hampton, G.C.B., D.C.L., President, in the Chair.]

It is now some years since so much was said and written about the load line. Members of this Institution will recollect how many Papers were read on the subject in this Hall, and also what a strong feeling was expressed by shipowners against any legislative interference. What was finally done was to empower the Board of Trade to require every owner to fix his own load line and mark it on the ship before every voyage, with a further mark on the side of the ship showing the level of the deck plank. It is thought by many well qualified to judge that this enactment has *pro tanto* had a beneficial effect. In most cases I believe the load line is not changed at successive voyages, but remains permanently painted on the topsides of the vessel, and as might perhaps have been expected there has been a certain general rule more or less closely observed as to so many inches of side for every foot of hold. But so far as my observation goes there is a different rule in different ports, and I think a freer side obtains in Liverpool, for example, than in some other ports. In any case the fact remains that steamers must now have a definite load line.

It is a question with some whether a freer side, or let us say a larger balance of surplus buoyancy, is an advantage or not,—whether or not such a steamer is more safe to navigate. Some authorities, for example, say that at a light draught more surface is exposed to the force of the wind, while others will urge that in some voyages and with grain cargoes it is all important to have your ship chock full. Again, it has been contended that a vessel deeply laden is less strained than one lightly laden. It has been put, for example, that were a ship laden until she was actually entirely submerged there would be no strains at all, but that every part would be in equilibrio and perfectly water-borne.

Let me shortly notice these conflicting views, and then submit to your consideration whether anything may or can be done to encourage, or rather to assist, or perhaps we should say *enable*, the shipowner to navigate his ship at the safest practicable draught.

From a sailor's point of view, common sense shows us that there is a just medium in loading, and that, though a very light ship may be like a bladder on the water, any captain would rather have 3 inches side per foot of hold than only an inch and a half. This will hardly be gainsaid, and in the same way as regards empty grain spaces, common sense will show us that by a proper arrangement of holds, each hold may be filled entirely with grain and at the same time a good side may be secured by leaving empty or air spaces at the ends of the ship. Therefore, as far as mere navigating is

concerned, candid minds will generally allow that steamers would be much safer to navigate if a better side were given than is the practice in some ports. For my own part I should not hesitate to say that in many cases the side allowed is far too little, and that it is of paramount importance to endeavour to check the deep loading which often prevails.

The contention that increased cargo lessens the strains is ingenious, but will not hold water. If a ship were a solid homogeneous mass, and always kept at rest, or at least always submerged, the extreme illustration is no doubt correct, but that condition of the problem is never found in any merchant steamer. On the contrary, a steamer's cargo is usually towards the ends, fore and aft of the engine space, and the amount of water-buoying is continually changing in amount and in position every minute. Besides, it must have occurred in the experience of every one of us that where ships have shown signs of weakness it has been when heavily laden. St. Paul relates, that "being exceedingly tossed with a tempest, the next day they lightened the ship," and surely this is what every modern sailor would like to do. Indeed I feel I must apologise for detaining you with these remarks, nor should I have done so had not two gentlemen within this year—both of great experience, one in Liverpool and the other in Newcastle—contended in conversation that a ship might be more deeply laden and yet the strains in a sea-way be less. Assuredly this is not the case with an ordinary merchant steamer, and just as certainly the temptation to overload is always very great and is increasing.

Three years ago I had the honour to read a Paper before this Institution upon "The Strains and Strengths of Ships," in which I sought to emphasize the importance in all mechanical construction of starting away from a correct basis. I think it was Mr. William John who first, before this Institute, compared the strength of ships by their displacement, and of the longitudinal strength by the simple formula of the *length multiplied by the displacement, and divided by the depth of the girder.* Since that time the subject has been discussed in many ways; and, so far as I have heard, no one has attempted to deny that the above formula is a very close and at the same time a very fair approximation, and I have little doubt but that sooner or later we shall see it adopted to a greater or less degree by all the Classing Registries.

At the last Autumn Meeting Mr. William Denny, one of our Members of Council, discussed this point, and I think came to almost exactly the same conclusion; and recommended, as I had ventured to do, that scantlings should be based on this formula. At the same sitting Mr. William John read a valuable Paper on the construction of ships, and so little was (as I apprehend) the drift of Mr. Denny's Paper understood that an able gentleman got up and said that the two Papers (Mr. Denny's and Mr. John's) were in direct antagonism! Mr. Denny's Paper was a searching criticism on the *basis* of rules for scantlings. Need it be repeated—yes it does need, I fear, to be repeated—that in everything a sure foundation is necessary—that in mechanical construction your calculations and your Tables must rest on a correct basis. The result of apportioning scantlings according to mere dimensions, and classifying ships accordingly, will most assuredly lead by a process like the natural selection of Darwin to productions in every way undesirable. It has indeed already done so.

I commenced by noting that every shipowner is now compelled to fix upon a load line, and I ask need this load line be now any longer a bugbear?

Speaking as a shipbuilder I know from experience that every ship, as a rule, has

her displacement calculated before she is laid down,* and I cannot but think that our Underwriting Societies might give us a "Permissive Bill" to base the major part of our scantlings on the displacement formula. It could not be anything but permissive, at any rate at first, since it would necessitate the entering of the load line in the Register Books. The immediate effect would probably be this. An owner has found that by making his ship 279 feet 6 inches long, and 34 feet 11 inches beam, and 24 feet 6 inches hold, he has a displacement, when the lines are *very* full, of 4,000 tons, with a dead weight of cargo and fuel of 2,700 tons, when loaded down to 21 feet. If he were allowed to increase his depth of hold without increasing his scantlings, he would probably try 6 inches more freeboard, and then in building again give, perhaps, finer lines and easier bilges. His underwriters, meanwhile, would note that one ship had 6 inches more freeboard than the other, and even if they did not at first make any difference in the rate of premium, they would note the fact and observe the results.

The "Underwriters'" Registry have since our last Easter Meeting taken a very important step, one of the most encouraging movements in this line which we have recently had to note. They have determined to base their scantlings mainly on the register tonnage under deck, with the necessary provision for local strengths. I trust that the Discussions in this Hall may have had some influence upon this step which they have taken. True it is only going back in principle to Lloyd's old system, but it is in one respect more satisfactory, inasmuch as the tonnage may be calculated beforehand if the builder submits the necessary sections. This gets rid of what always was more or less of a grievance and a difficulty, *viz.*:—that the class might be lost from overstepping a grade. Now were there a fixed *regulation* for surplus buoyancy it is evident that the present Rules of the Underwriters' Society based on the tonnage or cubic capacity would be exactly the same, or practically exactly the same, as the displacement basis. If a given per-centage of the cubical capacity be taken off the whole, and if that represents a fixed load line, then the displacement is arrived at, subject only to the difference between outside and inside measurement. As it happens however that there is not a fixed load line the Underwriters' Rule still taxes lightly-loaded ships. It also does not perhaps sufficiently recognize that in sagging and hogging strains *depth* is really an important element of strength, just as a *beam* is for racking strains, but at any rate it is a comfort to feel that steamers with fine entrances and clean runs are not to be classed, as regards scantlings, on the same footing as sea-going barges.

In conclusion, may I beg any one criticizing these observations not to imagine that I wish simply to reduce scantlings. On the contrary, my attention was first drawn to this subject by seeing a large highly-classed Atlantic steamer being stiffened in Liverpool after her first voyage, and since then I have repeatedly had reason to doubt whether the margin of strength in some of our very long and full steamers is such as prudence would recommend.

* It is said that some builders do not run out their displacements, but if this be so they at least estimate it by rule of thumb.

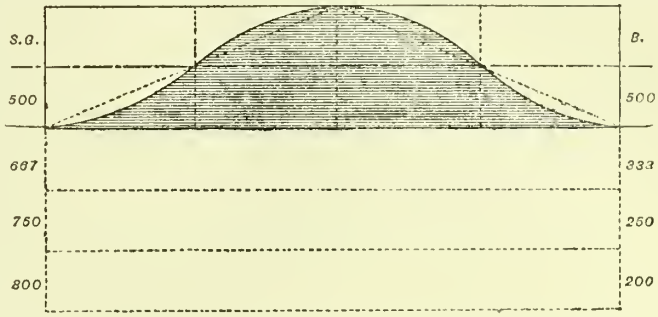
DISCUSSION.

Mr. F. B. Davis (Member): Mr. Richardson is not here, but I am sure he will feel flattered at any remarks that might be made respecting his ideas as read to you by me, and I shall willingly repeat them to him.

Mr. Benjamin Martell (Member of Council): If it were not for the name of Lloyd's Registry being mentioned in so many of the Papers I should really feel that it was in some degree a presumption on my part to stand up as I do on so many occasions, but I trust, feeling that I represent that Society and having to reply to these strictures, the Meeting will excuse me if I trouble them a little too much. Now, my Lord, we have heard, as Mr. Wigham Richardson says in his Paper, many Papers read on the load line of ships, and from all the Papers that I have heard read anywhere I have certainly been able to glean a little information—something to add to our stock of knowledge on the subject, because they have all been written by men who have been able and willing to add to our information on this difficult question. But it seems to me that if Mr. Richardson had striven as hard as he possibly could to prevent us deriving any information on the subject of his Paper he could not have succeeded more admirably, because there is not one point in the Paper with reference to the load line of steamers from which we can gain the slightest information, but it only seems to me to be a peg on which to hang a few remarks derogatory to the Registration Societies. *That* we know is a congenial theme with Mr. Richardson, and we are always prepared to hear from him remarks of that kind, but we can pass them by without further notice as far as they refer to the Society I represent. There is one thing in the Paper which gives me great satisfaction, and that is that Mr. Richardson takes special pains to tell us that he does not come forward on this occasion to advocate light scantlings. I am happy to hear it. It seems that he has reached this conclusion from something he has seen in Liverpool—from a ship which he has seen there which has shown him that it is possible to build ships too light. I hope that some others will also take the same precaution as Mr. Richardson, and will go and look at those ships, and then perhaps they will come to the same conclusion as he has.

Mr. W. W. Rundell (Associate): My Lord, I would make a few observations. I only regret that Mr. Richardson is not here to hear them, because they may not perhaps be considered of a complimentary character. I shall not pretend to say anything as to scantlings or their sufficiency, but I shall confine myself more particularly to matters relating to load line or rather to the strains among waves, but I hope to hear something from more competent persons as to the first part of the question also. I am not certain that my remarks will not touch Mr. Denny almost as much as Mr. Richardson, as he too appears to think that with a given displacement an addition to the freeboard of a vessel will not cause a greater strain at sea, but may be used as an additional plea for the reduction of her scantlings. However, to make a general remark by way of beginning, when Mr. Richardson tells us of a certain vessel that was lightened with advantage, I presume we must understand that this would depend very much on the part of the vessel from which the jettisom took place. If the vessel were heavily laden at the ends and cargo were taken from the ends, I daresay that would relieve her a great deal. We hear sometimes of vessels labouring in a sea-way having cargo taken out of their main hatch and being thereby very much improved in their behaviour, but I have a doubt about the correctness of such reports. To go into the matter a little, I confess I hold opinions which the writer of the Paper says will not hold water, and in speaking in support of these opinions I am somewhat oppressed by the feeling that I may gain the concurrence of only a minority of those present. In order to make good the position which I am endeavouring to put before you, I shall base my remarks on a Paper by Mr. John which he gave us I think in 1874. This Paper illustrates what we all know so well, the straightforward and luminous clearness of the remarks that Mr. John usually gives us at these Meetings. My extracts from Mr. John's Paper will be brief, and will bring forward as it were the propositions which are to form the basis of my remarks, and we are told in the Paper which we have just heard that it is very important to have a correct basis. They are shortly these:—"In still water the strains are due to inequalities between the weight and buoyancy in "different parts of the body of the ship." That is the main proposition. "If these did not exist in still "water they would be occasioned by the waves—we have to consider their magnitude and suddenness— "the higher and steeper the wave, if it be about the same length as the vessel, the greater the inequality

"between the weight and the buoyancy." Now I lay particular stress on that word "inequality." It shows us that we are not dealing immediately with the weight of the ship or the displacement of the ship, but something outside it, and Mr. Richardson seems to admit this in one respect, when he says—if the vessel were of the same specific gravity as the water there could be no strain because there is no inequality —there is nothing to make a strain. But he fancies when a ship has any amount of freeboard then there immediately ensues a strain that may be equal to the whole displacement of the vessel or to some multiple of the displacement. Now here we part company. I am of opinion that by increasing the cargo of a laden vessel we may lighten the strain, and therefore any argument for lighter scantlings with a given displacement because the freeboard is increased seems to me to be fallacious, because it seems to me that is just the very thing which makes the inequality, as Mr. John properly calls it, greater. By what steps will you go from having a certain amount of freeboard to no freeboard, from much strain to no strain— what graduation in comparison will you have except the gradual decrease of the freeboard, that is the spare buoyancy? Now we shall simplify our view of this matter if we look at the floating body as a homogeneous parallelopiped. Of course if we have a steamer, one for instance, comparatively light amidships and loaded with a heavy cargo at the ends, then we have a condition of great inequality even in still water; but at present we will merely look at the effect of freeboard among waves and to eliminate bad stowage we will presume, for the time, to treat the matter in its most simple form as a matter of difference of specific gravity only. In the accompanying diagram I show a homogeneous parallelopiped immersed as you will perceive to one half its bulk, that is the displacement is ·5, which is the specific gravity, or if we fancy water to be 1,000 units, the displacement of the vessel would be 500, and the scope that we have there for strains, that is the inequality which Mr. John refers to, will be there equal to or be limited by the displacement, because we have a spare buoyancy that is also equal to the displacement. Now in the Paper by Mr. John he places a vessel, as you will remember, so that her whole bulk shall be within the wave— that is, so that her whole bulk should be in the position shown by the parallelogram in the diagram. I do not know whether this is possible or if possible whether it ever occured with a ship—I have some doubt about it—but we can estimate by the diagram what the amount of the inequality can amount to, and we can show at once that it cannot be equal to the displacement. Each person here can calculate it for himself by looking at the figure. He will know that each quarter of the figure gives an inequality equal to about $\frac{2}{3}$rds of the particular section in which it is,* and therefore that the whole of the inequality will be equal to $\frac{2}{3}$rds of one half of the body, to $\frac{2}{3}$rds of the displacement, if we speak of weight in the present example; I prefer calling it $\frac{2}{3}$rds of the spare buoyancy, because that is the measure or limit of the inequality, as without spare buoyancy there could be no inequality. In still water there would be no strain. In the wave water the strain would be at its maximum when the vessel is in a wave of her own length and the wave reaches the top of the vessel. Mr. Richardson in his Paper ridicules the idea of lessening the strain by increasing the draught of the vessel. That is the point I now have to treat upon, and I hope to show you that as we decrease the spare buoyancy we shall decrease the strain due to this inequality—due to buoyancy. Let us double the size of the immersed portion of the parellelopiped by making the displacement of the diagram twice as great as it was before. We will still keep to the same units and speak only relatively as to size, because I want to avoid unnecessary particulars; we can generalise so as to make all the different figures in the diagram represent the same vessel. We now have two parts of the vessel immersed and one part out for spare buoyancy. The specific gravity will now be 667 parts out of the 1,000, and the spare buoyancy will as you see by the figures on the other side of the diagram be 333 units, that is to say 333 parts out of the 1,000. Taking $\frac{2}{3}$rds of this we make a strain or an inequality represented by 222 units. If we go on and still add to the immersion of the vessel, equivalent to putting more cargo on board, so that the displacement will be represented by 800 parts out of the 1,000, the spare buoyancy, as you can easily



* It will not be so much as $\frac{2}{3}$rds, ·57 is nearer the correct ratio—the rough approximation is used for simplicity merely.

calculate, will be 200, therefore the strain due to wave motion (that is confining ourselves here to the statical problem only, and not treating the matter dynamically at all, and I follow Mr. John in this matter in treating it as one of momentary equilibrium) will be reduced from $\frac{2}{3}$rds of 500 to $\frac{2}{3}$rds of 200. I hope I have at least made clear my idea that as we put the vessel deeper into the water the sea-strains are reduced. I say nothing of course of strains in a vessel unequally laden. Now this leads me to another remark, and I fear I may here have misunderstood Mr. John: if so, he will kindly correct me, for I do not at this moment know the steps by which the formula is obtained. In his formula he gives as his first factor the displacement, and he gives us no information to lead us to suppose that that first factor should be reduced in any way. You can easily see, by what I have said here, that if I were treating the same question I should multiply it, not by $\frac{2}{3}$rds of the displacement, but by $\frac{2}{3}$rds of the total bulk of the vessel minus the displacement. Take such a vessel as is shown in Mr. Denny's diagram (such a vessel will do very fairly for the example) where the total bulk would probably be about 8,000 tons. In my diagram I have put "registered tonnage" equal to 2,500 tons, say 8,000 tons for the entire displacement; take either vessel, that quoted by Mr. John has a displacement, that is ship and cargo together, of 5,000 tons. We take from the 8,000 the 5,000 displacement, and then we have 3,000 units for spare buoyancy; $\frac{2}{3}$rds of 3,000 will be 2,000, and that I take to be the possible strain due to the change in the form of the water or to the inequality. Now see, if this view be correct, how it tells upon something that appeared rather alarming at the time Mr. John read his Paper. He gives, as you will recollect, a maximum strain in some vessels on the upper part of the girder equal to 8 tons per square inch, but that was by taking the factor of displacement. If he had taken that of spare buoyancy instead he would have had to multiply 8 tons by $\frac{2}{5}$ths, which gives 3 tons and $\frac{1}{5}$th, so that the alarm as to the inadequate strength of iron ships as founded on this formula may possibly have been misplaced. It would have been very alarming indeed to have had a factor of safety of merely $2\frac{1}{2}$, as would then appear to be the case; but, if my view is correct, the factor of safety may be much higher than we were led to believe by Mr. John. Whether I have misunderstood the formula or not I trust that I shall have made clear to you my reasons for treating the strain among waves in a homogeneous body of ·5 or more specific gravity as dependant on the spare buoyancy, and not upon the weight of the vessel or the displacement.

Mr. WILLIAM JOHN (Member of Council): I think one or two words are due from me in reply to what Mr. Rundell has just said. I am not quite sure that I have followed Mr. Rundell entirely in his explanation, but, if I have, I take his meaning to be this: Mr. Rundell argues that the deeper a ship is, the more cargo she carries, the less she is strained.

Mr. W. W. RUNDELL: The greater the specific gravity of the ship.

Mr. W. JOHN: In other words, the deeper the vessel is in the water?

Mr. W. W. RUNDELL: Exactly.

Mr. W. JOHN: That is, the more cargo she has in?

Mr. W. W. RUNDELL: If the ship is loaded properly—it is the same thing.

Mr. W. JOHN: That the more cargo a vessel has the less she strains. That is a proposition which I cannot subscribe to. I am not sure that I followed Mr. Rundell in the introduction of another faction into the formula that he mentions which I once used here, and which I fear has been made far more of than I ever intended it to be; but, if I did rightly understand him, I think that he has introduced a fraction of $\frac{2}{3}$rds in some way to cover the proportion between the displacement and the total buoyancy of the ship. I will explain to the Meeting simply what I did to obtain the formula in question. I took a ship about 300 feet long, or rather over, and I placed her upon a series of waves—moderate waves they were—and I calculated section by section what the buoyancy was, and what the weight was, and I found from that the amount of the bending moment. I have done that with more than one ship, and testing the actual bending forces in that way, and finding that the actual strain from these specific buoyancies and weights came to about the displacement multiplied by a 35th of the length, I used that formula; but in using it I admitted it would probably require some alteration as you go from small vessels up to large vessels, and I should still hesitate to use that formula as one to which you could attach very great accuracy. I would not attach more importance than this to it—that it gives a rough idea of about the maximum amount of strain a vessel might be expected to have to sustain at sea. I think I see what Mr. Rundell means in one way, and I have found something similar on putting some of these ships on waves. You have a certain length of ship and a certain freeboard, and you find that the crests of steep waves of this length come up to the top of the deck forward and aft; when you get to waves of this steepness you

obtain a certain strain which is probably the maximum strain. Mr. Rundell says that if the ship were much deeper in the water you would not get such a wedge of buoyancy forward, or such a wedge of buoyancy aft, and therefore the ship would sink into it; but what you get in that case is that the waves break over the ship, and I think you are in a worse plight even than you are if you get sufficient buoyancy forward and aft. So that, while by sinking a ship in the water you might more or less reduce —I will go so far as to say—these bending strains under certain circumstances, yet it might be at the expense of the ship being in danger of being swept fore and aft. I do not know that I have any more to say, except that I wish to record here that the formula of the displacement multiplied by a 35th of the length is not a formula I am attached to, or put forward in any sense as being more than a very rough approximation to the strains on these ships at sea.

Mr. Henry Hartley West (Member): I will only say one or two words, not on the point Mr. Rundell has dealt with, but on a remark which occurs in the Paper itself. The author speaks of the alteration of the method of regulating scantlings which the Underwriters' Registry has adopted. I believe I am in a great measure responsible for that alteration, and as Mr. Richardson says it is simply a return to Lloyd's old system, I should like to point out that this is not the case. It is simply an adoption of a displacement basis in the most convenient form that you can get it. Mr. Richardson also says that the depth of girder is overlooked in the Underwriters' Rule, or that it is not sufficiently taken into account. Now the basis of scantlings that has been adopted by the Underwriters' Registry is the basis of tonnage, and the ratio of depth to length—the two combined, and with all deference I think it is one that fairly meets, as far as any simple numerical basis can be expected to do, the requirements of the case.

Mr. F. B. Davis (Member): There is only one observation I should like to make in reply to Mr. Rundell. It appears to me he must have misunderstood Mr. Richardson's idea. I presume if Mr. Richardson were here he would reply to Mr. Rundell's observations to the effect that he did not consider loading a ship deeper added anything to her strength—in fact, the strength of a ship is in the hull, and not in the cargo—there is no portion of the strength in the cargo. It does not follow that putting more cargo in the ship adds to the strength of the hull; in fact, it gives the hull a great deal more work to do, and consequently Mr. Richardson should be right in the idea that the lighter a ship is loaded the more able is she to bear the strains put upon her. That is the only observation I have to make.

ON AN APPLICATION OF THE DECIMAL SYSTEM OF MEASUREMENT IN PRACTICAL SHIPBUILDING.

By Henry H. West, Esq., Chief Surveyor to the Underwriters' Registry for Iron Vessels, Member.

[Read at the Nineteenth Session of the Institution of Naval Architects, 11th April, 1878; E. J. Reed, Esq., C.B., F.R.S., M.P., Vice-President, in the Chair.]

The particular application of the decimal system to which I invite your attention, is the use of that system for the measurement of the scantlings of iron vessels; and by scantlings I mean the two dimensions of *breadth* and *thickness* of the various parts of the structure of a ship.

A serious obstacle to the general adoption of decimal measures has hitherto been the great difficulty of deciding on a common unit which shall be equally convenient for all measurement purposes. Unfortunately such a unit is not likely to be found, and if we are to secure any of the advantages of a decimal system without legislative enactment, we must accept the unit which, for any particular kind of measurement, we find ready to our hands.

Shipbuilders are not without a precedent for such a course. In that happy adaptation of the decimal system which we know as the tonnage laws, the *foot* was unquestionably the most convenient unit, for the particular purpose, that could have been proposed; and being both convenient and familiar, it was adopted without difficulty.

For the measurement of scantlings the unit in universal use is the *inch*. This, then, must be our integer, and the only change which I propose from the present system of notation, is that *fractions* shall be measured and recorded decimally to the second or third place of figures, instead of binarily as at present.

I think we may all readily admit that there will be no difficulty in changing the written description of an angle iron frame from $4\frac{1}{2} \times 3 \times \frac{8}{16}$ inches to $4{\cdot}5 \times 3 \times {\cdot}5$ inches, or of a sheer strake from $40 \times \frac{12}{16}$ inches to $40 \times {\cdot}75$ inches, or of a floor plate from $24\frac{1}{2} \times \frac{10}{16}$ inches to $24{\cdot}5 \times {\cdot}625$ inches.

A shipbuilder's routine calculations are usually made in decimals, and those members of his staff upon whom devolves the duty of making such calculations, will appreciate the advantage of having all their measurements of material recorded in decimal terms without the trouble of conversion.

But if saving a few figures in a reckoning, or increasing the facility of checking an invoice of iron, were all that this use of the decimal system could offer, I should not be justified in occupying your valuable time on its consideration. It has other and more practical advantages.

In the scantlings of iron vessels the more important fractions occur in the

dimension of thickness, and as it is only with fractions that the decimal notation is concerned, it is to this dimension that we must direct our principal attention.

It has hitherto been the practice to measure the thickness of iron plates and bars in sixteenths of an inch, and the practical result of this has been to limit the variations in thickness of shipbuilding iron to steps of one-sixteenth of an inch. Indeed, this minimum variation has been so long and so universally accepted, that it comes down to us with all the authority of a tradition of the elders—a tradition which, whether for good or for evil, the Rules of Lloyd's Register and of the Liverpool Book have done much to strengthen and make absolute. Thus in the range of thicknesses in ordinary use, any alteration whatever involves a change of not less than 7, and it may be of as much as 25 per cent.

The unequal incidence of this state of things upon thick iron and upon thin iron is too palpable to need any comment. Even the smaller per-centage, when it affects large quantities, is much too wide a step, and is one which, while it hampers the freedom of design of the true naval architect, offers a premium to the man who can cleverly manipulate a ship's form and dimensions to suit the Rules of the Classification Societies.

It is desirable in this connection to form some idea of the effect upon the weight and cost of an ordinary merchant steamer, produced by an alteration of one-sixteenth of an inch in the thickness of all the items of scantling, excepting rivets and forgings.

In the construction of the hull of a screw steamer of 1,000 tons register under deck about 500 tons of iron would be used, and this amount of material would be distributed approximately, as shown in Table I. This Table shows also the approximate mean thickness of the various items of scantling; the per-centage ratio, which one-sixteenth of an inch bears to that mean thickness, and the weight which would accrue to, or be deducted from, each item by an alteration of one-sixteenth of an inch in its thickness.

TABLE I.

Items of Scantling.	Per-centage of Gross Weight.	Weight in Tons.	Approximate mean thickness of each item in sixteenths of an inch.	Ratio per cent. which one-sixteenth of an inch bears to mean thickness.	Difference of Weight in Tons by a variation of one-sixteenth of an inch in thickness.
Forgings (keel, posts, rudder and hold stanchions)	4	20	...	...	...
Frames, reverse frames and lugs	12	60	6	16·7	10·0
Floor plates	5	25	8	12·5	3·1
Beams (bulbs and angles)	6	30	6·5	15·4	4·6
Keelsons (plates and angles)	7	35	8·5	11·8	4·1
Deck stringers and ties	10	50	8·5	11·8	5·9
Shell plating	38	190	9	11·1	21·1
Rivets	6	30	...	...	...
*Remainder (plates and angles)	12	60	6	16·7	10·0
Totals	100	500	...	...	58·8

* Does not include erections on deck or water ballast.

By an inspection of this Table, it will be seen that we have a total difference of 58·8 tons. This, at the price of £7 10*s.* per ton, represents a value for material of £441. But shipbuilders always tell me, when I have to perform the unpleasant duty of asking for an extra sixteenth, after their contracts are signed, that each ton of weight added, is not simply at the cost of so many pounds sterling for material, but that the labour account is affected in a like degree; in fact, that as surely as each ton weight of iron in the original ship costs a definite average sum for labour, so surely will each extra ton, embodied in the extra sixteenth, cost for labour a similar sum. Without fully endorsing this, I accept it as fairly representing the shipbuilders' view of the subject, and as sufficiently accurate for the immediate purpose of illustration. Taking then the cost of labour at the present time at about an average rate of £4 10*s* per ton weight, we have to add to the sum of £441 for material, a labour charge of £264 12*s.* Shipbuilders' profits just now, appear to be so small that they are hardly worth adding as a separate charge, but without this, and without any addition for proportion of fixed charges, we have already a difference of cost of £705 12*s.* In other words, by making the smallest recognised difference in the thickness of the iron used in her construction, we have altered the cost of a steamer of 1,000 tons under deck by upwards of 14*s.* per registered ton.

This is a serious evil, but the ingenuity of the Classification Societies has done much to ameliorate it. At a very early date in the history of iron shipbuilding, the authorities of Lloyd's Register adopted, in a partial degree, the system of making the different items of scantling dependent upon different dimensions and proportions of the ship, so that only in exceptional cases should all the scantlings advance simultaneously; and of late years, under the stimulating influence and example of the Liverpool Registry, they have considerably extended the practice.

The principal difficulty, however, has always been with the shell plating, representing, as it does, the chief part both of the weight and of the strength of the vessel. To meet this difficulty the following compromise was adopted. In the year 1870 the Rules of the Liverpool Book were published with a difference of one-sixteenth of an inch in the thickness of the inside and outside strakes of shell plating. The practical effect of this arrangement was to halve the ordinary step of one-sixteenth. Two years later a similar provision was made in the Rules of Lloyd's Register.

But however *convenient* this arrangement may be, it can only be looked upon as a compromise. It is, in fact, making compensation for a series of thin plates in one place by putting a series of thick plates in another place; and after all has been done which ingenuity can suggest, there still remain turning-points in the Rules of both the British Registries at which by a trifling modification of form or dimensions a vessel passes from one category of scantlings to the next higher or lower, involving material alteration in both weight and cost.

This is so generally understood that I need not occupy your time with more than one or two illustrations.

[Table.

TABLE II.

	A.	B.
	Feet.	Feet.
Length per Rules	256·5	256·5
Breadth moulded	31·9	32·2
Depth to top of keel	22·25	22·295
Half-midship girth	34·7	34·7
Lloyd's 1st numeral	72·9	73·095
Lloyd's 2nd numeral	18698·85	18748·867
Depths to length	11·5	11·5
Depth to top of floor	20·375	20·375
Depths of hold to length	12·5	12·5
Registered tonnage under deck	1199·	1201·

TABLE III.

Items of Scantling.	A. Weight in Tons.	B. Weight in Tons.	Difference of Weight in Tons between Steamers A and B.
Forgings (keel, posts, rudder and hold stanchions)	23·7	25·8	2·1
Frames, reverse frames, and lugs	73·0	76·1	3·1
Floor plates	33·8	35·0	1·2
Beams (bulbs and angles)	41·9	43·6	1·7
Keelsons (plates and angles)	44·0	48·1	4·1
Deck stringers and ties	64·6	64·6	...
Shell plating...	241·6	256·9	15·3
Rivets (taken at 6 per cent. of the gross weight)	38·1	39·9	1·8
Remainder (plates and angles) say ...	75·0	75·0	...
Totals	635·7	665·0	29·3

I have given in Table II. the dimensions, tonnage and other particulars, of two nearly identical steamers, A and B. I have calculated the weight of iron in the hulls of each of these vessels, on the basis of the scantling requirements for the highest class, both at Lloyd's and at the Liverpool Registry. These weights are given in Table III.; and it will be observed that while the difference between the two vessels, as shown in Table II. (which is a Table of Dimensions), is only nominal, in Table III. (which is a Table of Weight) it takes the very material form of nearly 30 tons of iron. If we convert this nto money, by the same method of valuation as was adopted before, we have a difference of cost, between A and B, of £351 12*s.*, or nearly 6*s.* per registered ton.

Of course the secret of all this is that the slight alteration in the breadth of the second vessel places her just outside the enchanted circle of regulations by which the scantlings of the first vessel are determined. The same thing occurs in a greater or

less degree at each of the artificial boundary lines, by which the Classification Societies have divided the various types and sizes of vessels into groups. There can be no doubt that the Rules will have provided adequate strength for the most extreme case which can occur in each group. It therefore follows that the steamer B would be carrying about with her, during the whole term of her life, some 30 tons of useless material. Thus there is a shipowner's as well as a shipbuilder's view of this question. Such a vessel as A or B would ordinarily make some eight round voyages per annum, and if we take the freight at the moderate computation of £2 5*s.* per ton, for the round, we have an annual sum of £527 8*s.*, made or lost, according as an owner has adopted A or B as his type of vessel.

We cannot wonder then in these days of keen competition if every clever device is adopted by which the form and dimensions of any proposed new vessel may be so manipulated as to secure the maximum carrying ability with the minimum scantlings which the Rules of the Registries will allow.

By the kindness of some of my shipbuilding friends, I have had placed at my disposal, the weights of iron in a considerable number of vessels. From these I have selected as further illustrations of this point, two three-decked vessels C and D, particulars of which, as built, are given in Tables IV. and V.:—

Table IV.

	C.	
	Dimensions in Feet.	Weight in Tons.
Length between perpendiculars	255·0	
Breadth moulded	33·0	
Depth of hold	23·2	
Registered tonnage under deck	1538·0	
Lloyd's 1st numeral	72·8	
Lloyd's Rule turning point for 1st numeral ...	73·0	
Lloyd's 2nd numeral	18454·	
Lloyd's Rule turning point for 2nd numeral ...	18700·	
Forgings (keel, posts, rudder, and hold stanchions) ...		28·0
Frames, reverse frames, and lugs		94·0
Floor plates, keelsons, and water ballast		108·6
Beams (bulbs and angles)		66·3
Deck stringers and iron decks*		134·5
Shell plating		280·0
Rivets		45·0
Remainder (plates and angles)†		113·0
Totals	...	869·4

Note.—The addition of 5 inches to the depth of hold would increase the numerals so as to add about 25 tons to the weight.

* Iron decks are in excess of the Rules.

† Does not include erections on deck.

TABLE V.

	D.	
	Dimensions in Feet.	Weight in Tons.
Length between perpendiculars	286·0	
Breadth moulded	34·5	
Depth of hold	24·25	
Registered tonnage under deck	1889·	
Lloyd's 1st numeral	75·78	
Lloyd's Rule turning point for 1st numeral	76·0	
Lloyd's 2nd numeral	21559·	
Lloyd's Rule turning point for 2nd numeral ...	21700·	
Forgings (keel, posts, rudder, and hold stanchions) ...		34·2
Frames, reverse frames, and lugs		100·6
Floor plates, keelsons, and water ballast		144·2
Beams (bulbs and angles)		70·5
Deck stringers and iron decks*		157·5
Shell plating		312·0
Rivets		45·0
Remainder (plates and angles)†		143·0
Totals	...	1007·0

NOTE.—The addition of 3 inches to the depth of hold would increase the numerals, so as to add about 35 tons to the weight.

Both these vessels have Lloyd's highest class, and you will see that the numerals, in each case, are very cleverly managed to get the largest ship that could be had within the limits at which scantlings would be increased.

The question now arises, Is there any remedy for this state of things? I believe there is; and that a remedy will be found in the general adoption of the decimal system for the measurement of the scantlings of iron vessels.

In a Paper read before the Institution of Mechanical Engineers, in the year 1857, Sir Joseph Whitworth proposed a decimal sheet-and-wire gauge. This is the first record I have found of any systematic attempt to establish a decimal notation specially for thickness. Instead of the confused system of wire gauges then prevalent, indicating the sizes by arbitrary numbers, which did not in themselves convey any idea of thickness, Sir Joseph proposed a gauge which should have the various notches marked by numbers expressing their size in thousandths of an inch. For the finest gauges of wire and sheets the advances are by steps of ·001 inch. This interval is gradually increased till, at and from ·300 inch, the advance is by steps of ·025 inch up to ·500 inch, which is the present limit of the gauge.

Here then we have a decimal measure of thickness carried to the third place of

* Iron decks are in excess of the Rules. † Does not include erections on deck.

figures; a measure which has been some years before the public, and which, though not as widely known as its great merit deserves, has nevertheless a recognised position and value as a standard.

One of the first steps to be taken in reducing the anomalies which we have been discussing, is to increase the number of different thicknesses of shipbuilders' iron; and by the decimal system this may be done to any degree. By the simple extension of Sir Joseph Whitworth's gauge from sheets to plates we should secure, in the range of ordinary shipbuilding iron, where at present we have only ten variations of thickness, no less than twenty-five different sizes, varying by the very appreciable thickness due to 1 pound weight per superficial foot.

It will perhaps be thought unnecessary to multiply divisions beyond this limit; and this is one of the points upon which I would specially invite the expression of your opinion. It is, however, clear that such multiplication is capable of indefinite extension, if it should be found necessary or desirable.

Any method of regulating scantlings which has been largely adopted must have had some merit, either of practical convenience or of scientific propriety, to enable it to live; and fairly good rules should not be lightly disturbed. But, while I am no iconoclast, I cannot but feel that the hard and fast lines of demarcation, so characteristic of all the systems of rules which have hitherto prevailed, are a radical vice; and though judicious administration has done much, and may do more, to modify their inequality and soften their injustice, these defects will be inherent in any system which does not recognise this general principle—that any departure from a limit of size or proportion should be met by a proportionate, and *only* a proportionate, alteration of scantling. So long, however, as we reckon by sixteenths this will be impracticable; but with the general adoption of the decimal system a complete reform in this respect will be gradually but infallibly accomplished.

I must not pass from this branch of my subject without some reference to steel. The good qualities of the modern form of this material have secured for it a favourable reception at the hands of the shipbuilding profession; and the principle appears now to be generally admitted that some proportional reduction should be made in the scantlings of vessels built of steel from those of similar vessels built of iron. Such a reduction can only be effected with accuracy either by the use of inconvenient and unfamiliar vulgar fractions or by the adoption of decimal measures. In this case there can be little hesitation as to which should be chosen.

For convenience of reference I have prepared two Tables (VI. and VII.) the first of which gives the ordinary binary fractions of sixteenths, thirty-seconds, and sixty-fourths, with their decimal equivalents and the nearest hundredth and the nearest thousandth. The other gives the weight per foot in pounds and the number of superficial feet per ton of iron of various thicknesses, advancing by steps of twenty-five one-thousandths of an inch. The weight is calculated on the ordinary basis of 40 pounds to the square foot 1 inch thick. Steel may be taken, I believe, at about $2\frac{1}{2}$ per cent. heavier.

[TABLE.

Table VI.

Binary Fractions.			Decimal Fractions.			Binary Fractions.			Decimal Fractions.		
64ths.	32nds.	16ths.	Nearest Second Place of Figures.	Nearest Third Place of Figures.	Exact Equivalent.	64ths.	32nds.	16ths.	Nearest Second Place of Figures.	Nearest Third Place of Figures.	Exact Equivalent.
$\frac{1}{64}$	...	...	·02	·016	·015625	$\frac{33}{64}$	...	...	·52	·516	·515625
	$\frac{1}{32}$	...	·03	·031	·03125	...	$\frac{17}{32}$	...	·53	·531	·53125
$\frac{3}{64}$	...	...	·05	·047	·046875	$\frac{35}{64}$	...	...	·55	·547	·546875
		$\frac{1}{16}$	·06	·063	·0625	...	...	$\frac{9}{16}$	·56	·563	·5625
$\frac{5}{64}$	...	...	·08	·078	·078125	$\frac{37}{64}$	...	...	·58	·578	·578125
	$\frac{3}{32}$	...	·09	·094	·09375	...	$\frac{19}{32}$	...	·59	·594	·59375
$\frac{7}{64}$	...	...	·11	·109	·109375	$\frac{39}{64}$	...	...	·61	·609	·609375
		$\frac{2}{16}$	·13	·125	·125	...	...	$\frac{10}{16}$	·63	·625	·625
$\frac{9}{64}$	...	...	·14	·141	·140625	$\frac{41}{64}$	...	...	·64	·641	·640625
	$\frac{5}{32}$	...	·16	·156	·15625	...	$\frac{21}{32}$	...	·66	·656	·65625
$\frac{11}{64}$	...	...	·17	·172	·171875	$\frac{43}{64}$	...	...	·67	·672	·671875
		$\frac{3}{16}$	·19	·188	·1875	...	...	$\frac{11}{16}$	·69	·688	·6875
$\frac{13}{64}$	...	...	·20	·203	·203125	$\frac{45}{64}$	...	...	·70	·703	·703125
	$\frac{7}{32}$	...	·22	·219	·21875	...	$\frac{23}{32}$	...	·72	·719	·71875
$\frac{15}{64}$	...	...	·23	·234	·234375	$\frac{47}{64}$	...	...	·73	·734	·734375
		$\frac{4}{16}$	·25	·25	·25	...	...	$\frac{12}{16}$	·75	·75	·75
$\frac{17}{64}$	...	...	·27	·266	·265625	$\frac{49}{64}$	...	...	·77	·766	·765625
	$\frac{9}{32}$	...	·28	·281	·28125	...	$\frac{25}{32}$	...	·78	·781	·78125
$\frac{19}{64}$	...	...	·30	·297	·296875	$\frac{51}{64}$	...	...	·80	·797	·796875
		$\frac{5}{16}$	·31	·313	·3125	...	...	$\frac{13}{16}$	·81	·813	·8125
$\frac{21}{64}$	...	...	·33	·328	·328125	$\frac{53}{64}$	...	...	·83	·828	·828125
	$\frac{11}{32}$	...	·34	·344	·34375	...	$\frac{27}{32}$	...	·84	·844	·84375
$\frac{23}{64}$	...	...	·36	·359	·359375	$\frac{55}{64}$	...	...	·86	·859	·859375
		$\frac{6}{16}$	·38	·375	·375	...	...	$\frac{14}{16}$	·88	·875	·875
$\frac{25}{64}$	...	...	·39	·391	·390625	$\frac{57}{64}$	...	...	·89	·891	·890625
	$\frac{13}{32}$	...	·41	·406	·40625	...	$\frac{29}{32}$	...	·91	·906	·90625
$\frac{27}{64}$	...	...	·42	·422	·421875	$\frac{59}{64}$	...	...	·92	·922	·921875
		$\frac{7}{16}$	·44	·438	·4375	...	...	$\frac{15}{16}$	·94	·938	·9375
$\frac{29}{64}$	...	...	·45	·453	·453125	$\frac{61}{64}$	...	...	·95	·953	·953125
	$\frac{15}{32}$	...	·47	·469	·46875	...	$\frac{31}{32}$	...	·97	·969	·96875
$\frac{31}{64}$	...	...	·48	·484	·484375	$\frac{63}{64}$	...	...	·98	·984	·984375
		$\frac{8}{16}$	·5	·5	·5	...	...	1 inch	1·00	1·00	1·00

Table VII.

Thickness of Iron in Decimal Fractions of an Inch.	Weight per Superficial Foot in Pounds.	Number of Superficial Feet per Ton.	Thickness of Iron in Decimal Fractions of an Inch.	Weight per Superficial Foot in Pounds.	Number of Superficial Feet per Ton.
·025	1	2240	·525	21	106·6
·050	2	1120	·550	22	101·8
·075	3	746·6	·575	23	97·3
·100	4	560	·600	24	93·3
·125	5	448	·625	25	89·6
·150	6	373·3	·650	26	86·1
·175	7	320	·675	27	82·9
·200	8	280	·700	28	80
·225	9	248·8	·725	29	77·2
·250	10	224	·750	30	74·6
·275	11	203·6	·775	31	72·2
·300	12	186·6	·800	32	70
·325	13	172·3	·825	33	67·8
·350	14	160	·850	34	65·8
·375	15	149·3	·875	35	64
·400	16	140	·900	36	62·2
·425	17	131·7	·925	37	60·5
·450	18	124·4	·950	38	58·9
·475	19	117·8	·975	39	57·4
·500	20	112	1·000	40	56

In urging the merits of a decimal system for the measurement of scantlings, I have been met by the objections that there would be insuperable difficulties at the ironmakers' works; that it would be impracticable to roll plates to these finely-graduated measures, and that the apparatus employed at the rolling mills does not admit of such great accuracy. It has further been urged that our workmen would be completely at sea amongst any measures except those ordinarily marked on a two-foot rule.

I confess that these objections are neither as numerous nor as formidable as I had expected to hear. The supposed difficulty at the rolling mills is not a serious one. The universal custom at present is to roll plates, not by dimension of the thickness, but by gauge; and a certain per-centage above or below the standard is allowed as a margin for error. If then the same margin per cent. is allowed, it is as easy to roll to one gauge as it is to roll to another, and the whole matter resolves itself into a simple question of gauge-making. I have applied to leading iron makers, in all the principal iron districts, to learn whether this would involve any practical difficulty or inconvenience that would affect the price. Without exception they have replied that, if shipbuilders generally adopted the practice of ordering their iron in decimal measures there would be no difficulty whatever at the iron works in supplying those orders at the usual rates. I have similar replies from the leading steel-making firms.

We have already seen that it is the dimension of *thickness* with which decimals are principally concerned, but this is just the dimension with which the shipyard workman has nothing whatever to do. Each piece of iron is marked for the position in the ship which it is intended to occupy, and the workman has simply to fit the

material provided for him to its own particular place, without any reference to its thickness. Thus decimal measures need only be dealt with by a trained staff of draughtsmen and clerks who, both by education and daily practice, are thoroughly familiar with decimal arithmetic.

Friends, who have perhaps been less careful in forming their opinions than candid in expressing them, have said that an unreasonable surveyor would make difficulties over every plate he could find which might be half-a-hundredth of an inch too thin, but would quite overlook all those plates which might be as much too thick. I can only say in reply to this that the way in which a man's rule is divided will not alter his character; and that there is always an appeal from an unreasonable surveyor to a reasonable Committee. Of *bonâ fide* errors I for my own part have no fear. My experience of them is that they cancel one another, so that if they do not exceed that limit which we must accept as a proper allowance for unavoidable error, they are of no importance.

I have endeavoured to show how the application of the decimal system to the measurement of scantlings may be made to remedy some of the grave defects inherent in the present method. The simplicity of the change is such that I look forward to a time, at no distant date, when it will be generally adopted by the shipbuilding profession; and if by drawing your attention to this subject I have in any way assisted towards the accomplishment of so desirable a reform, my end will have been gained.

DISCUSSION.

Mr. William Denny (Member of Council): Mr. Chairman, I would say that so far as Mr. West's Paper goes in the direction of desiring to have a fresh system of measurement introduced, I am heartily at one with him. It is altogether upon the line of obliterating, if possible, the harsher differences which are natural to any empirical category of numerals or measurements. But while I agree with Mr. West in this matter, and congratulate this Institution on the Paper and on the fact that one of the Registration Societies is willing to consider it in spite of all its difficulties, yet at the same time I am sorry that I am not able altogether to agree with his colleague, Mr. Rundell. Mr. Rundell has traversed the displacement basis, which I have shown to-night has really been worked upon by Lloyd's, and I think he has traversed it to a great extent without reason. I think Mr. John in taking up the subject has taken it up very moderately, and without any desire to push his own personality too far in the matter, but I think it is not too much to say that Mr. Rundell has altogether exaggerated his own argument.

The Chairman (Mr. E. J. Reed, C.B., F.R.S., M.P.): I am unwilling to interrupt, but we have another Paper to read, and you are going to discuss the previous Paper again. The Paper we are discussing is "On the Application of the Decimal System of Measurement in Practical Shipbuilding," and I would ask you to kindly keep to that. You are now answering the speeches on the former Paper.

Mr. W. Denny: Very well, Sir, I bow to your decision.

The Chairman: I am sure the Meeting will agree with me that we can hardly in a discussion of this Paper, which is one directed to a specific point, go back to the discussion of a former Paper, for then we should never get through our work. If that were not so I am sure I, like everybody else, would be delighted to hear an extension of Mr. Denny's remarks. Before we proceed to the next Paper, as no one else has offered to speak, I desire to thank Mr. West, and I know I shall have the concurrence of the Meeting in so doing, for a Paper which I consider is a very good type indeed for this Institution—a Paper which deals with the future progress of our Profession, and in the composition of which great pains have been taken to bring facts together with the view of guiding our judgments. I am sure that some of the Tables here given will be very convenient, to say the least of them.

ON THE NICOLAIEFF FLOATING DOCK:

The Origin of its Design, Construction, Experience in Docking Vessels, and Future Development.

By Captain E. E. Goulaeff, F.R.S.N.A., Russian Imperial Navy, Member.

[Read at the Nineteenth Session of the Institution of Naval Architects, 11th April, 1878; E. J. Reed, Esq., C.B., F.R.S. M.P., Vice-President, in the Chair.]

The Committee appointed to investigate the question of stability of the *Inflexible*, in their published Report, made the following important recommendation :—

"We note that the beam of the *Inflexible* was limited by the consideration of the "width of the docks available for her repair, but we doubt if this consideration ought "to outweigh the great advantages which a further increase of beam would give to "vessels of the *Inflexible* type. We are the more inclined to doubt it because at present "docks capable of accommodating vessels of any breadth can be constructed of iron "rapidly, and at no serious cost in comparison with that of such vessels as the "*Inflexible*."

Now, exactly the same considerations as this last paragraph of the Report on the *Inflexible* were guiding the august head of the Russian Navy, the Grand Duke Constantine, when, two years ago, His Imperial Highness sanctioned the order of the Nicolaieff Floating Depositing Dock to be built by contract by Messrs. Clark, Standfield & Co., at the recommendation of Admiral Lesovsky (who had then just entered the office of Minister of Marine) and of Admiral Popoff.

At that time we possessed already a large amount of experience in lifting vessels out of water. The original two-sided docks at Kronstadt were built of wood. Their continuous and successful working not only in lifting ships out of the water, but also in carrying large men-of-war for a distance of some 20 miles from St. Petersburg to Kronstadt, across the bar of the Neva, led to the subsequent construction of the sectional iron floating dock, also for Kronstadt harbour; it is in five parts, each 65 feet long and 81 feet wide inside, and continues to answer its purpose extremely well.

It was decided accordingly that the Nicolaieff Dock should be also a floating one.

To make clear the circumstances attending the origin of the design of this new floating dock I cannot but refer, for a minute or so, to the state of ideas existing at that time in respect to naval architecture, as these ideas are very closely connected with the subject of dock construction.

Just then the invention of circular iron-clads produced a new and most important era in the design of vessels; because, by practically illustrating the laws which regulate the motion through water of bodies of such forms, which had not previously been adopted and tried, it offered to the world the possibility of considering, not only upon

hypothetieal data, but with deeisive results in hand, how far that pure eireular form could be modified with advantage when the objeets of the naval design were different from those whieh had to be satisfied when the *Novgorod* was planned. As the old ships of a quarter of a eentury ago formed for Mr. Reed, the late Chief Constructor of the Royal Navy, one point of departure, so the popoffka *Vice-Admiral Popoff* beeomes, aeeording to the expression of the same authority, another; and I have no doubt the design of short and broad ships, at this moment and in this eountry, oeeupies the minds of many.

Indeed, who can fail to reconsider his former opinions on the subject, when it is remembered that the *Minotaur*—a vessel of a length equal to about seventeen times her breadth—steams with the same speed as does the *Inflexible*, one-half shorter, without any considerable differenee in her engine power; when we now hear, from one of the greatest seientifie authorities of the day, that aeeording to the experiments at Torquay, the resistanee of the last vessel, when moving with the full speed, would have been diminished, had she been made proportionally but half the length of the *Minotaur*.

We believed and believe in Russia in a still greater inerease of beam in the vessels of the future, and aeeordingly it was deemed necessary that the new doek should be made eapable of accommodating not only vessels of the forms whieh were and are now so extensively adopted both in the Navy and in the Mercantile Marine, but also vessels of those shapes whieh are likely to be used in the future for speeial purposes. It is only doeks whieh satisfy both these eonditions whieh ean never beeome obsolete, since they alone ean never present any obstacle to the adoption of the eonstant and wonderful improvements in modern naval eonstruction, as the existing graving docks in all eountries undoubtedly have done.

At the time of seleeting the system of doek for the Nieolaieff, through political causes we possessed in the Blaek Sea only two small eireular iron-elads, an Imperial yaeht, and no other ships of the Navy worthy of note. The largest of the eircular vessels was one of 3,600 tons, whilst the length of the long vessel was less than 280 feet. These two figures settled the principal dimensions of this dock.

Messrs. Clark and Standfield's system showed the dock composed of a long structure, the transverse seetion of whieh represented the letter L subdivided longitudinally into two parts, so as to allow the doeking of one-half of it upon the other half for the purposes of repairs or painting. An outrigger was attaehed to the vertical side of this L-shaped dock to insure its stability, notwithstanding its unsymmetrieal form. A number of equidistant slots were formed in the horizontal arm of the L, so as to admit, when the doek was moved elose to the shore, of its passing between a corresponding number of piles, forming the gridiron staging, erected along the river frontage. By sueh means as were more minutely deseribed by Mr. Latimer Clark, C.E., two years ago, in his able Paper on the same subjeet, read in this very Hall, vessels doeked upon sueh a doek might be deposited on the stages, while the doek itself beeomes onee more free for doeking other ships, and, if neeessary, for depositing them similarly, if sufficient provision be made in the extension of the gridiron stages. This eonstituted the new great idea of Messrs. Clark and Standfield for a Depositing Doek, adapted mainly for use in commercial rivers and ports, where place could be found for sueh staging. It was intended ehiefly to reduee the expenses of docking, by having only one floating strueture, the construction of whieh required considerable outlay, with

perhaps ten or twenty cheaply-constructed wooden landing stages for the simultaneous repair of any number of commercial vessels.

At the time when the Russian Government were about to order this dock, no consideration of the immense facilities which such docks offer for the development, or rather for not restricting the growth of iron-clad construction, seemed to enter into the minds of the inventors of the Depositing Dock. It was Admiral Popoff who, always having before him the possible changes in the future form of vessels, advised the inventors to make their proposed dock not in one piece, transversely, but to separate entirely the vertical arm of the letter L from the horizontal one, and to form the latter of a number of separate and independent pontoons, possessing appliances for their further extension in length when necessary, and acting somewhat in the same manner as the independent air bags so extensively adopted in the north of Russia, and which are described in *Engineering*, October 29th, 1875. And indeed, the action of the Nicolaieff Dock pontoons may be very well compared to that of the air bags, with the difference, however, that in the dock there is a common removable connection between such air bags in the form of what is called the lateral side, which contains the whole of the machinery necessary for the convenient working and controlling of the dock when submerged. Thus, the Nicolaieff Dock shaped itself at the time of its design into the following independent parts:—

1. A lateral side, together with the floating outrigger, attached to it by means of a parallel motion.

2. Ten pontoons, constituting the main lifting power of the dock, and the means for depositing. There is provision made on the lateral side for fourteen such pontoons.

Besides the sub-division of the dock, the lateral side is formed of three parts, each capable of acting independently for the purpose of docking upon each such part, with its corresponding number of pontoons attached to it, or upon a combination of two such parts, either smaller vessels or the remaining third part of the dock.

For long vessels all three parts of the dock are combined and joined together in one continuous line, and for the existing circular vessels some of the pontoons are detached from the lateral side, and joined to the outer unconnected ends of those pontoons which remain in the middle portion of the dock attached to the lateral side, thus transforming the area of the dock from a long, comparatively narrow shape, shown in elevation in Fig. 1 (Plate IV.), into a short and broad one as shown in plan in Fig. 2, and in end elevation in Fig. 3.

Fig. 4 shows the dock submerged, ready for docking a long vessel; Fig. 5 shows the vessel docked; and Fig. 6 the same vessel deposited on the staging.

The size of the Nicolaieff Dock is, as I have already mentioned, small; but that size satisfied our wants at the time, and the Minister of Marine desired to make only the smallest possible demands upon the budget. But suppose we require to dock the *Peter the Great*, it would be necessary only to join to the outer ends of the existing pontoons ten more new pontoons, a little longer than the existing ones. The second side, with the floating outrigger, might be added, and such an addition will give the advantage of having practically two independent docks, each powerful in itself, and which can be stationed at two distant ports, and which would require to be joined together only in the event of docking such exceptionally large vessels as the *Peter the Great* or the *Inflexible*.

Thus it may be truly said that the extensibility of the Nicolaieff Dock in any direction is without limit, and this constitutes the chief peculiarity and the advantage

of this system; the depositing principle, however valuable in respect of economy, forms, according to my opinion, a matter of only secondary importance from a naval architect's point of view.

All parts of the dock are now launched, completed and tested, at Nicolaieff, having been previously erected at Millwall.

As there was no special necessity to vary much the pitch of the rivets throughout the dock, the plates used varying only from $\frac{3}{8}$ to $\frac{1}{2}$ inch in thickness, Mr. Standfield adopted a nearly uniform pitch of $2\frac{1}{2}$ inches everywhere for the outer skin, the water-tight decks and bulkheads. As the number of holes to be punched throughout amounted to more than 2,000,000, the greater part of the punching was done by means of a double punching machine, capable of perforating three holes at once, the distance between which was set at $2\frac{1}{2}$ inches; by this machine an accuracy was gained far surpassing that of hand work, which depends so much on the skill and the eye of the workman. This accuracy proved to be of great service, especially when riveting the structure after its second erection at Nicolaieff.

The method of connecting the pontoons to the lateral side, as well as of the pontoons between themselves, may be understood by the help of diagrams Fig. 7, 8 and 9. Fig. 9 is a vertical section taken at the line C C in Fig. 7. On the lateral side of the dock a rectangular frame is formed, projecting about 1 foot, the height and breadth of this frame being equal to the height and breadth of the pontoons. The outer edge of this frame is surrounded by an angle iron 5 inches $\times$ 5 inches $\times$ $\frac{3}{4}$ inch with holes $1\frac{5}{8}$ inches drilled carefully at a pitch of 4 inches. At each end of the pontoons a corresponding half chamber is formed by placing its end bulkhead about 1 foot farther back than the end of the pontoon. When these two half chambers are brought together they enclose a space sufficiently large to admit men to enter and screw up the bolts which unite the pontoon and the dock together. As regards the bottom and sides these bolts are screwed from within the chamber, but on the top of the pontoon they are placed on the outside so as to be more easily accessible. As soon as the two parts of the dock to be joined are approached to each other as closely as practicable, the bolts in the upper outside angle irons are introduced through the corresponding holes and screwed up. When this is done, two or three men enter the pontoon, through one of the manholes A in the deck of the pontoon, and pass through the manhole B made specially for the purpose in the end-bulkhead, into the connecting chamber, now formed by the two half chambers above described, and screw in the connecting bolts along the side angle irons in the interior of the chamber, starting from the upper part and gradually descending by ladders down to the water-level. By this time the india-rubber band with which the outer edges of the pontoons are provided becomes so jammed in its place as to prevent any further ingress of water from the outside, and accordingly the water, which has been shut inside the chamber, may now be pumped out, thus allowing the men to descend still lower and to screw together the remaining parts of the connecting angle irons, and to complete the joint. The three portions of the lateral side of the dock itself were actually joined together in a similar manner after having been built separately and launched separately. The strength of these joints after the dock was completed was tested most severely, and ascertained to be perfectly satisfactory. The practical joining of the pontoons and of the parts of the side did not present any difficulty, as an accurate correspondence of the holes for the connecting bolts had been attained by careful attention to the workmanship, and though the pontoons were built in different places and away from each other and from the lateral side, all the con-

nections were found to correspond perfectly, even when joined together indiscriminately. Each single pontoon when floating independently will owing to its form float on its side, and therefore, in order to get it into its proper vertical position ready for connecting to the dock, it is necessary to right it. This is done by the introduction of water into the lower part by means of valves or cocks, and of four pipes which pass through the pontoon from end to end. The action of righting was beautifully illustrated when one of the pontoons, built on a shipway vertically, was on being launched into the water seen to turn gradually over on its side, and was afterwards artifically brought up to the former vertical position by additional water. Over the four middle chambers of each pontoon there are special compartments or air chambers at the top, separated from the rest of the pontoons by means of horizontal water-tight decks. Thus, if any of the cocks, which control the introduction of water for the purpose of righting the pontoon, should happen to leak, the pontoon cannot sink, as the air chambers afford sufficient buoyancy and retain it in its proper vertical position.

The buoyancy afforded by these air chambers was so designed as to exceed somewhat the weight of the iron used in the construction of the pontoon, and practice proved that the calculations were on the safe side, as it was found impossible to submerge the dock perfectly level when all the air chambers were closed. It is decided now to keep them open as soon as the pontoons are attached to their places.

Fig. 10 shows the longitudinal section of the pontoon. The bulkheads and decks marked W T are water-tight. Diagonal stiffeners D, three on each side of the central bulkhead, are introduced just beneath the point corresponding with the keel of long vessels when docked. Each compartment of the pontoons, as well as those of the lateral side, is braced with vertical and horizontal transverse and longitudinal stays of angle irons 4 inches $\times$ 4 inches $\times$ $\frac{1}{2}$ inch.

Fig. 11 shows the general arrangement of piping intended for pumping out the dock, or letting the water in.

The lateral side of the dock, longitudinally, is subdivided into compartments 15 feet and 5 feet alternately: the 15-feet bays corresponding with the pontoons attached to the side. In each third portion of the dock two of the 5-feet bays or wells are occupied by pumps and gear. In the upper portion of each third there is a 25-horse portable steam engine, mounted on fixed foundations and provided with double pulleys, which convey motion first to two intermediate horizontal shafts, and thence by means of the conical spur wheels to vertical shafts of the pumps. The pumps are placed right in the bottom of the pump wells, so as to obviate any loss through suction up to any unnecessary height. They are centrifugal pumps, Woodford's patent, 2 feet 4 inches in diameter, taking water from below at the centre, and driving it to the circumference by means of only two stout blades, made of cast steel. A special friction gear is fitted to the upper part of the jacket of the pump. The friction rollers in this arrangement are of steel, and are intended, whilst reducing friction, to convey the pressure due to the weight of the vertical shafting to the body of the pump, instead of transmitting it wholly to the lower bearing of the shaft.

To each pump there is a discharge tube leading from its circumference to the outside of the dock. As I said before, the water is conveyed to the pumps from below. The suction tube is provided with two valve boxes arranged in one transverse line. These boxes contain the main regulating valves for the pontoons, and the action of each of them consists in opening or shutting, simultaneously, four orifices of the piping leading from the pontoons; all these orifices or terminations being arranged in one

horizontal plane. One of these valves opens or shuts four pipes leading from the compartments of those halves of the two pontoons, adjacent to this particular pump, which are nearest to the side of the dock, whilst the other valve regulates the pumping of the compartments of those halves of the same two pontoons which are further away from the side of dock. Thus each portion of the dock, corresponding to every two pumps, is sub-divided into four quarters, and the rise and fall of each quarter can be regulated easily with great nicety. As there is common connection between all pumps, of which I shall speak presently, it will be evident that the rise and fall of the four corners of the whole dock, in whatever order arranged, either in one part, or in two parts, or in three, may also be governed with the same precision. For pumping out of the lateral side of the dock itself there are special pipes, which branch off from each pump into the compartments of the side adjacent to the particular pump-well. These pipes are connected with the common suction tube leading to the pump, and the motion of water through them is regulated by means of separate sluice valves. The discharge is governed by means of Kingston valves, and by an additional external flap-valve which works inside the strainer surrounding the discharge orifice. Rods connected with the main-regulating valves, opening and shutting each four pontoon pipes, rods of the Kingston and rods of the sluice valves governing the pumping out of the side, are all carried up to the upper deck of the side of the dock, and being there supplied with indicators are worked according to the Captain's orders from the top of the dock. When the water is being pumped out the flap-valve above mentioned opens automatically by the increased pressure of water in the discharge tube compared with the pressure outside the dock: but should any injury occur to the engines, pumps or piping which delayed the flow of water out of the discharge orifice, then the flap-valve closes automatically, and prevents the outside water from entering in the dock, whether the Kingston or other valves described be opened or not at that moment.

Besides the main regulating valves, which govern the flow of water out of the pontoons, each pipe leading from the pump wells to the different compartments of the pontoons is provided with its own cock, the rods of which are carried up to the engine and upper deck; these cocks allow us to isolate any water-compartment of the pontoon from the action of the whole dock, in case such a compartment is punctured or its corresponding pipe choked.

Thus the whole operation of pumping out or letting in the water is controlled altogether by four independent means, *viz*:—1*st*. Separate cocks in each of the pontoon pipes. 2*nd*. Main-regulating valves. 3*rd*. Kingston valves. 4*th*. Flap valves. All prevent any mishap occurring to the dock through inattention, or any other cause, thereby ensuring its perfect safety at any moment of the operations.

The letting of water into the dock is performed in a manner reverse to the pumping out, and the water flows in by natural outside pressure.

The air from the pontoons, when the water is let in, is carried away from the top of every compartment by means of short pipes running over the pontoon decks and thence ascending up along the lateral side of the dock.

To complete the description of the system of pumping arrangement it is necessary only to mention that, as the three parts of the dock are provided with separate steam engines, separate pairs of pumps, separate means for controlling the whole operation of pumping water out or letting it in, it was necessary to connect together these three independent groups, when all parts of the dock are joined together, in order to obtain

uniformity of working throughout. This is performed by two rows of main pipes, running between the pumps the whole length of the dock. Such an arrangement ensures equal level of water in the whole dock, in a longitudinal sense; and, as means are provided to close and open such connections at will, these pipes perform the same duty when only two parts of the dock are put together for docking small vessels.

There is another advantage offered by the existence of the main-connecting pipes, as it allows us to use any of the three engines, or any two of them, to pump out any pontoon without reference to the part of the dock to which it corresponds.

As all pontoons are interchangeable, and provided at either end with connecting angle irons with holes and india-rubber band, it was necessary to fit them with piping running from one end to the other, so that if this or that end of the pontoon is approached to the side of the dock, or to the end of another pontoon, it is possible not only to screw the joint tight, but also to connect the piping. This is done by means of india-rubber hose, with couplings similar to those used for connecting the pipes of the fire engines.

Every part of the dock is provided with its independent capstan, the system of which was designed specially by Harfield & Co., so as to occupy the smallest possible room athwart-ship, and also in order to take the chains from both ends of each third of dock.

The upper iron deck of the pontoons is provided with oak-timbers, rigidly secured to the deck by means of angle irons. Keel blocks, of oak, and sliding bilge blocks are carried upon these timbers. The sliding bilge blocks are worked from the upper deck of the side of the dock by means of chains.

The first trials consisted in testing the action of one-third of the dock by docking a large floating crane, weighing at the time of trial 800 tons. By calculating from the extra freeboard of the dock with this crane on it, the Commission of Officers of the Nicolaieff Dockyard, appointed for the purpose, reported the contract lifting power as having been satisfactorily attained.

The stability of the dock, upon which some doubt at first was entertained by unprofessional persons, who judged only by the want of the second side, proved in practice to be immense. Captain Brovzin, to whom the dock is at present entrusted, and who has been for years working the Kronstadt Docks, which have two sides, expressed not only his entire satisfaction with regard to the security and ease of the manipulation of the Nicolaieff Dock, but was perfectly delighted to find that he was not compelled to go in a boat round and round the dock to watch the horizontality of its submersion, and to signal up to the engineers of the dock, until he and his officers were quite tired. In this new Nicolaieff Dock the Captain, being on the upper deck, had only to observe the position of the outrigger to be enabled to judge of the transverse level, and to observe the two gauges placed on the extreme ends of the dock, to judge of the exact longitudinal deviation from the horizontality. Thus the level may be kept to an inch, and was kept so in our first trials, though now we have become careless enough to let the dock out of level for 6 inches or so.

Only few and infrequent words of command from the captain to the sailors stationed near the handles of the different valves are necessary, and I myself sometimes played with submerging the first part of the dock, being the only person on deck.

The whole operation of lifting the crane so high up as she was lifted continued three and a half hours, but the time in which the bottom of this vessel was clear out of the water, and therefore actually docked, was little over two hours.

When the second third of the dock was next launched and completed it was joined to the first third; and both parts, having six pontoons only attached to them, were employed for docking the steamer *Ingool*, which, being a vessel of comparatively small displacement, was lifted out of water and lowered down again in about seven hours, including the time necessary for repairs to her screw-propeller.

The next vessel docked was the S.S. *Russia* (the one which soon after brought to Sebastopol the valuable prize Turkish steamer *Mersina*). There was a great wish on the part of the Government to have her docked for the purpose of cleaning before she proceeded to sea, whilst it was impossible to wait until the last third of the dock was completed in fear that the vessel might be blocked by ice in Nicolaieff. Thus an unusual attempt was made—an attempt which is explained only by the military situation. A vessel of 334 feet long was lifted upon a platform, offered by the dock, whose total length did not exceed more than 174 feet. Accordingly enormous overhangs of the extremities of the vessel were left unsupported. To this circumstance, another difficulty was added—three pontoons, out of the six employed for this operation, were attached to the lateral side so that the distance between them was 5 feet, whilst the distance between the remaining three at another end of the dock, was 25 feet, as shown on Fig. 12. Such an arrangement of pontoons evidently brought the centre of lifting power for a considerable distance away from the middle point of the length of the dock and therefore, supposing that the centre of gravity of the vessel was situated in the middle point of the length, she could not have been placed, with equidistant overhangs of her extremities so as to bring her centre of gravity just over the centre of lifting power. Some difference in the extension of overhangs of the bow and stern was consequently allowed for the purpose, but this allowance was not such as to bring sufficiently near the centre of gravity to that of the lifting power for fear of increasing too much the forward overhang which was already great. Accordingly the vessel, though her estimated weight was corresponding nearly exactly to the lifting power of the six pontoons used on the occasion, was lifted, so as to leave her keel and the lowermost part for 2 feet 8 inches in the water. It was measured that at one end of the lateral side of the dock there was 5 feet of water whilst in the other end there remained no less than 21 feet unpumped; the mean height of the unpumped water was therefore 13 feet, whilst for equilibrium only 7 feet ought to have been left, had the dock been placed in a position to develop its full lifting power. Evidently a corresponding amount of similarly distributed unpumped water was remaining in the pontoons, but that also could not have been pumped out, without inclining the vessel. However some inclination was allowed and nearly the whole part which was at first remaining in water was scrubbed and painted down to the upper part of the keel, leaving only a small portion in the middle not cleaned.

The *Russia*, after having been thus docked, showed no sign of structural weakness, notwithstanding the enormous overhangs, fully proving Admiral Popoff's confidence in the strength of iron ships, in view of which he took upon himself to recommend the docking of the *Russia* on two parts of the dock only.

In concluding this Paper, I cannot help referring to the excellent workmanship throughout the construction, and the great care bestowed by Mr. Standfield in improving the design and execution of all the details connected with this dock—which, taken as a whole, certainly forms one of the most beautiful monuments of modern engineering science, and will reflect the greatest credit upon the firm of Clark, Standfield & Co.

DISCUSSION.

Mr. Henry H. West (Member): I should like to ask what type of vessel the *Russia*, docked in that extraordinary way, was and whether there was any sign of straining at the points immediately over the extremities of the supports—straining of the ship I mean? It is not a question of the dock, so much as a question of the ship that was being docked under those extraordinary circumstances.

Mr. Standfield: When the vessel was docked the Chief Engineer of the Russian Company was on board, and although there was an apparatus on board to indicate if any sag took place, no sagging could be observed.

Mr. H. H. West: There was no mark of straining on the side of the ship?

Mr. Standfield: No.

Mr. H. H. West: Was she a merchant vessel?

Mr. Standfield: Yes, she was one of the largest vessels of the Russian Steam Navigation Company.

The Chairman (Mr. E. J. Reed, C.B., F.R.S., M.P.): As no one else appears to desire to take part in the discussion of this Paper, I should like to say one or two words before we separate. The general reflection that suggests itself to one is, how much better it is for Russian officers and naval architects and dock inventors to unite themselves in the productions of works of this kind instead of fighting with war ships. I hope myself that the owners of this dock may never have to dock the *Russia* for the purpose of sending her out against British ships, for I hope we may remain in the amicable relations in which we now are. This dock seems to me to evince the characteristic boldness of Admiral Popoff as a Russian designer, and the characteristic skill, and I might say the characteristic genius, almost, which Messrs. Clark and Standfield have exhibited in the various designs of these docks, because I understand from the Paper that the dock may be considered to be the joint production of Admiral Popoff and Messrs. Clark and Standfield, because I see one or two of the particular features of this dock were suggested by Admiral Popoff. It really is a dock that must strike the mind of everybody accustomed to floating docks as an exceptionally remarkable one, both from its characteristics and also apparently from the great advantage which it confers. In the first place, it seems to dock itself—as I happen to know, having seen it in progress—which is an excellent quality in a floating dock. In the next, it docks very short ships—the extremely short ships of Russia, the circular iron-clads. Then, in the next place, it docks long ships, not only in the exceptional manner exhibited in Diagram 12, which was occasioned by having to dock a long vessel prematurely, before the other part of the dock was completed, but in a manner in which it receives proper and uniform support throughout its length, so that no question of straining arises in the ordinary use of the dock. It not only seems to dock short ships and long ships, but it seems to dock several ships; for, being formed as shown here, it is capable of landing ships after it has raised them on stages such as is shown in Diagram 6. Then it seems also to possess the immense advantage of being very extensible—you can add to it by following out the principles on which you originally designed it, and so adapt the form of dock to the vessel which you wish to take in, by merely adding to it new parts. Then it has the great advantage of being portable. It seems to be economical in its construction, being all plain and straightforward work; and it seems also to have the great advantage of accessibility both inside and outside, the latter, of course, by its self-docking power, and the former by an arrangement which is explained, so that every part is easily accessible if it is required to be painted. I saw this dock when it was originally being erected on the Thames, at Poplar and I noticed with much pleasure the point which has been referred to in the Paper, namely, the use of the multiplying-punch for punching off the work. Certainly the work was most admirable, and I am not at all surprised to find that in actual use the dock has elicited the encomiums which Captain Goulaeff has passed upon it. I have thought it right, as Chairman for the moment, to make these remarks, because one of the objects for which we founded this Institution was to promote improvements such as are embodied in this dock, and to get recorded in our *Transactions*, for the benefit of our Members, the results of actual trials. I think we are alike indebted to Captain Goulaeff for so promptly sending us this full and valuable description of the dock after its completion, and also the results of the trials which have been made with it, and to Messrs. Clark and Standfield, for having, as I know they have done, furthered

in every way the placing of the Paper before us in the finished manner in which it has been presented. I do not know whether it is to Captain Goulaeff or to Messrs. Clark and Standfield we owe these beautiful diagrams, but I suppose it is to the English firm; and, if so, I am sure the Meeting would like to return them thanks, because they have contributed very much to the value of the Paper. I hope that we may ask those gentlemen to convey to Captain Goulaeff for us—and perhaps, if it is possible, Mr. Woolley, our Secretary, will also take the opportunity of doing it officially—the thanks of the Meeting for having favoured it with this valuable contribution.

Mr. LATIMER CLARK: I may add that the dock has been in one sense commercially successful. The vessel *Mersina*, taken by the steamship *Russia*, is said to have been of very much greater value than the dock itself.

ON THE ROYAL NAVAL COLLEGE AND THE MERCANTILE MARINE.

By W. John, Esq., Surveyor to Lloyd's Registry of British and Foreign Shipping, Member of Council.

[Read at the Nineteenth Session of the Institution of Naval Architects, 12th April, 1878; the Right Hon. Lord Hampton, G.C.B., D.C.L., President, in the Chair.]

The want of an establishment in this country suitable for affording a scientific and technical training to young men outside the Government Service desirous of becoming shipbuilders or naval architects has long been felt, and it has often been discussed before this Institution with more or less favourable results. It is well understood that this Institution contributed in no small degree towards the establishment of the Royal School of Naval Architecture at South Kensington, which has now become embodied in the far larger and more comprehensive Institution since organized at Greenwich and known as the Royal Naval College.

When the movement took place in this Institution in reference to the establishment of the Royal School of Naval Architecture and Marine Engineering, one of the important features of the scheme then proposed was to make the school available for private students from the Mercantile Marine, as well as for Admiralty students from the Royal Dockyards. This was, in fact, to be one of the special features of the new school, in which it would differ from the two schools of naval architecture that had previously existed under the auspices of the Admiralty. Another new feature was the training of marine engineers in conjunction with naval architects. The last feature has to my mind been very successful. I can say for myself that I value highly the fact that during my course of studies at South Kensington I was associated with engineers as well as shipwrights following a somewhat similar line of study. We who were training for naval architects picked up a good deal from the engineers about engines and boilers that we might not have done otherwise, and probably the engineers picked up from our course of study a good deal about shipbuilding that might otherwise have escaped them.

The other special feature of the school to which I have alluded, *viz.*, the training of private students, did not I am sorry to say prove so successful at South Kensington. Many praiseworthy efforts were made by the Science and Art Department to foster and develope the uses of the school in this direction. The scale of fees was placed comparatively low, free-studentships were offered, and later on scholarships of £50 a year were offered for competition to private students, but all these inducements failed to attract real support from the private shipbuilding establishments of the country. Private students it is true came to the school, and some of them obtained free-studentships, others succeeded in gaining scholarships, but for the most part those students came fresh into the school without previous connection with the private

shipbuilding yards, or previous professional training, and not a few entirely failed to obtain during their course of studies a sufficient technical knowledge to enable them to obtain employment, or gain a livelihood by the profession they had chosen. There were exceptions of course. I could point with pleasure to more than one former private student at Kensington who is succeeding, after having started with immense disadvantages; and they certainly well deserve to succeed,—but in spite of this fact, few will deny that this branch of the Kensington School, *viz.*, the training of private students for the mercantile marine was a comparative failure.

Since the absorption of the School of Naval Architecture in the Royal Naval College, there have been no English private students entered in it. Foreign students have availed themselves of the advantages of the College training, but English students of Naval Architecture have not done so. The favourable reception given to Mr. White's interesting Paper at our Glasgow Meeting last Autumn, however, affords better hopes for the future. There are, however, I believe, a few private students undergoing a preparatory course of training to enable them, hereafter, to enter the College with fair prospects of being able to complete the course. And there is more than a prospect of a movement in this direction being encouraged by the establishment of scholarships by others than the Government, to be offered for competition to private students. The time therefore seems opportune for discussing more fully than was done at Glasgow, or than has yet been done, so far as I know, the position of our Mercantile Marine, in relation to this question of the technical education of private students at the Royal Naval College.

I cannot claim to speak with much authority on the subject, for neither regarding the Mercantile Marine, the Admiralty Service, nor in matters of technical training, is my experience to be compared with that of many Members of this Institution; but this I can say, that I have looked at the subject at successive periods of my life from entirely different points of view, and I have very often thought over the question, how the advantages of the College training could best be secured by the Mercantile Marine. I am sure the oftener the subject is discussed in this Institution, the better it will be understood; and I trust, therefore, the Meeting will grant me some indulgence while I lay before them some opinions I have formed on the matter. I would much rather be able to lay before you matters of substantial fact or scientific investigation, than matters of opinion, but on this subject absolute demonstration is an impossibility.

I feel one difficulty in dealing with this subject, and I may as well state it at once. It seems impossible for one who has studied at the School of Naval Architecture, to talk freely about the advantages to be derived from such a training without some appearance of egotism, and this I am naturally anxious to avoid. None, however, can know the advantages of systematic teaching in Naval Architecture better than those who owe their positions and any progress they have made entirely to this cause. If it were a generally accepted proposition that a Naval College training would be an unmixed advantage to any young man intended to become a private shipbuilder or Naval Architect, I should be relieved from this difficulty, but then most of the difficulties of the whole question would also have been removed. I feel sure, however, that if we could poll the shipbuilders of the country we should find a considerable majority of them would not admit anything of the kind, and it is by no means so easy a matter as might be supposed to convince them otherwise. I have often talked the matter over with people who quite appreciate scientific teachings, but who urge that the three years spent at the College would be more profitably spent in the shipbuilding yard in acquiring a knowledge of

business and a proficieney in the practical work of the yard and in obtaining by practice greater facility in draughting and designing. They argue that a knowledge of curves of statical and dynamical stability, and curves of shearing forces, bending moments, &c., is purchased at too high a price by devoting three years to the study of them, especially as when acquired they could be of little use in the ordinary work of the private shipbuilding yard.

A knowledge of the calculations in ordinary use, such as displacement, tonnage, metacentre, and the easiest methods of estimating weights is easily picked up in the mould loft or drawing office; and the greatest difficulty I see is to convince private shipbuilders and others wishing to bring their sons up to the profession, that the additional knowledge obtained at the Royal Naval College is worth to them the time, trouble and expense of acquiring it.

I am not speaking now of the opinions of those who pretend that a scientific training renders a man incapable of applying his common sense to practical questions or to ordinary matters of business. This is an old tradition that long remained a powerful lever to be used against technical training, but it has fortunately lost its force in the present day, and clings only to the minds of a very few. Not so, however, the question I have raised as to the length of time over which the College course extends. That is discussed frequently and soberly. Many young men have expressed to me a desire to be able to enter the College for a year or perhaps two, not with a view to enter upon a course of higher mathematics, but to devote themselves as far as possible to acquiring as sound a knowledge of ship calculations as their previous mathematical training would admit of. Personally I should be much gratified if the College could be made available for students of this kind for short terms. They would come direct from private shipyards, and would probably have acquired a knowledge of drawing, laying off, and ordinary calculations before entering the College, and with a little help in mathematics and ship calculations they might spend the short time at their disposal for College work very profitably indeed.

The advantages which would arise from affording facilities of this kind to private students would I conceive be very great, even if it were regarded only as a temporary expedient. It would bring about a closer connection between the Naval College and the Mercantile Marine, which in itself would be an immense advantage, and it would remove misapprehensions that at present exist respecting the College. Those who at first attended a partial course of instruction would soon get to appreciate the advantages of the complete course; and it would I think tend gradually to bring about a desire on the part of others who followed them to qualify themselves, by previous hard study, for undertaking the higher branches of the College training.

I know the difficulty that arises in carrying out such a scheme as this is, that students entered in this way for a partial, or comparatively speaking elementary course, would not fit in well with the existing classes of properly prepared students, and they would therefore have to form a separate class, which might necessitate an increase in the College staff. Dr. Hirst, F.R.S., the director of studies at the Royal Naval College, who has probably taken more interest in, and given more thought to this subject than any one else, and who certainly is the highest possible authority on what can be done in this way at the College, very kindly pointed out to me these difficulties, and I was very sorry to learn from him that they were so great. He was of opinion that the only practicable way of extending the advantages of the College instruction in Naval

Architecture and Marine Engineering to the Mercantile Marine, was through the admission of a class of private students, as thoroughly prepared to receive instruction as the Admiralty students are who join the College after a mixed practical and elementary theoretical training received in the dockyards; and Dr. Hirst had, he said, reasons for believing that such a class was attainable, and that the ultimate effect of concentrating College efforts upon their thorough education, would be to turn out a number of highly and generally well-trained Naval Architects and Marine Engineers, with good results to the professions.

In still dwelling on the question of admitting private students for short terms, it will be understood from what I have said that I fully appreciate the difficulties in the way of carrying it out to so great an extent as I have indicated; but it is, I know, the wish and desire of many to see the College training rendered as elastic as possible in this direction, and the point is well worth discussion; for I feel sure Dr. Hirst and all who assist him in carrying on the important work of the College would gladly extend the facilities afforded by the College so far as practicable to meet the requirements of the Mercantile Marine, if it can be made clear to them that it would help the private students, and that the training of their own Admiralty students would not be impaired thereby.

There is another point to which I attach great importance in reference to the training of private students. It is that they should have the means, during the College course, of acquiring a good groundwork of professional knowledge suitable especially for the Mercantile Marine. This was scarcely the case at South Kensington. The inner working of the private building yards, the docks, and the repairing yards were brought but little under the notice there of either the private students or the Admiralty students. Now this I hope will be amended in the new scheme for the admission of private students at the Naval College. I speak on this point with some degree of confidence, because, in common with many who were Admiralty students at that School, and have since become engaged in matters relating to the merchant navy, I have experienced the vast change there is in passing from Admiralty work and war-ship design to the Mercantile Marine. It is true the scientific principles involved are absolutely the same in both services, but I have no hesitation in saying that a student leaving the School after a course of studies such as we had at South Kensington might have a very good knowledge of the mathematical principles as they apply to the Royal Navy, and yet have, for a time, wrong conceptions of how far to apply them advantageously to the Mercantile Marine. This is more important than it seems, or I would not press it on the Meeting. A young man leaving the College has, unless he is especially fortunate, to start with encountering a certain amount of prejudice, more or less openly expressed. He is, almost necessarily, at first less expert than others of his years in matters of detail and business, and if his scientific bias, if I may so term it, leads him to run counter to the practical instincts of those around him, he is likely for some time to find his special training at a discount. Any one, for instance, entering a private yard, having an idea that the determination of the metacentric curves, curves of stability, &c., are as necessary for the ordinary merchant vessels under construction there as they are for a modern iron-clad, would, I fear, be looked upon as having imbibed ideas of *negative* rather than *positive* worth.

These are but samples; I could mention features amounting almost to principles relating to structural strength, stowage, load-line, and other things, in which the

requirements for the Mercantile Marine differ materially from the requirements of the Admiralty Service, and it is a most essential matter to my mind that these should be well impressed upon private students during their College course.

At South Kensington we had professional instructors as able as it was possible to find them, and the Naval College is not less fortunate in this respect. No one can appreciate the talents of these instructors more than I do, and I believe they will quite agree with me that there should be a considerable—a marked—difference in the training of an Admiralty and a private student, when they advance beyond that point at which they begin to learn the application of scientific principles to their respective callings. At the South Kensington School the English private students used to spend their summer vacations in the Royal Dockyards like the Admiralty students. I hope in the future means may be concerted for enabling them to spend their summer months in some of the private shipbuilding yards of the country; and, more than this, I hope they may also visit, under intelligent guidance, the repairing yards when work of especial interest is in hand there, and become more or less acquainted with the daily work about the docks.

A student should, I conceive, during his three years' course of study be able, in addition to advancing his scientific knowledge, to obtain a better general knowledge of his profession than if he spent the same time in any one yard whatever; that is, his eyes should be opened more to the main features and tendencies of his profession; the lines of thought that are gaining ascendancy and those which are becoming out of date, might well be imparted to him so as to give him clear ideas as to the directions in which improvements are to be looked for. I am sure that by means of teaching by the instructors, and of lectures, this was done for the Admiralty students at South Kensington most thoroughly, and is, I believe, being done at the Naval College far better than it could be done at any dockyard. I hope equally suitable training will be afforded in the future for the private students, so that they may learn more real professional work at the College and during the summer vacations than they could do if permanently attached during an equal period of time to any one private shipbuilding yard in the country.

I am told that no difficulty will arise in extending the course of study to types of ships other than those with which the Admiralty are mostly concerned. A broad field for useful teaching of this kind is presented by the Mercantile Marine. Between the great Atlantic steamers and the small craft about our coasts there are hundreds, I may say thousands, of merchant ships of varying forms and dimensions designed to fulfil certain purposes of trade. From many points of view the actual numbers and variety of the structures so presented must be a source of embarrassment; but they really follow certain definite laws and types, and to a great extent they contain the very lessons which mark the stages of progress that it is most necessary to bring home to the minds of students. To teach mercantile ship design in its broad sense these are considerations that should have much prominence, and would greatly advance the future of the private student.

While a modern iron-clad is in herself a structure of such enormous complication that a merchant ship by comparison appears a mere shell, it should not be forgotten that for one iron-clad afloat there are hundreds of merchant ships, differing from each other in size and form, and intended to fulfil different conditions in different trades. While, therefore, it may be right and proper for two or three Admiralty students to be

engaged for months in preparing together the designs for a particular iron-clad, and making all the necessary calculations for her, the course to my mind with private students, would be to abridge somewhat the calculations and multiply the number of types of ships they can be made practically aquainted with; and by the help of suitable data to render them fit to do useful work as soon as they leave the College. It should always be borne in mind that while the design for a war ship is a work of months, and her building is a work of years, a merchant ship usually has to be designed and contracted for in a few days, and completed in a few months. I do not for a moment lose sight of the fact that the College is not the place to teach a student the details of shipbuilding, and I must have expressed my meaning badly if I have conveyed such an impression. Primarily the College must concern itself with the teaching of scientific principles, with supplying the tools as it were to the student for his future use; but there is a certain extent to which the application of those principles must also be taught, and I have endeavoured to show the direction which, in my opinion, this teaching should take to render it of the greatest assistance to private students in their future careers. There will always remain abundance of scope for them to fill in as it were the details of such a training after leaving the College.

I have alluded to the prospects of scholarships being founded for private students entering the Royal Naval College. I am able to mention that the Committee of Lloyd's Register have already promised to contribute a sum annually to establish special scholarships for assisting private students studying at the College, and I believe other such scholarships have been talked about in connection with one or more of our chief mercantile shipbuilding districts. The Government also I doubt not will promote a movement in this direction with the same liberal hand they gave evidence of at South Kensington, and where all interests are thus combined, the project can surely be brought to a successful issue. It must always be remembered, however, that scholarships such as those to be offered are useful chiefly in assisting and inducing promising young men to enter the College, who otherwise might not have sufficient means to avail themselves of the College training. They failed, however, to attract the attention of the mercantile world to the School of South Kensington, and they will fail again unless a feeling of confidence in the practical utility of those scientific principles imparted by the College training, can be instilled into those who look to becoming themselves, and those who look to bringing members of their family up as private shipbuilders and naval architects. The object of my Paper has been to assist, if possible, towards bringing about this desirable object, and if it tend towards this end in the smallest degree, it will be to me a source of satisfaction and of pleasure.

DISCUSSION.

Dr. Joseph Woolley (Vice-President): My Lord, I have very few remarks to offer, but what I have to say chiefly tends to confirm what Mr. John has said in his Paper with regard to the extreme difficulty that was felt in the establishment at South Kensington in attracting any interest whatever from the mercantile world outside the Admiralty. As Mr. John very properly observed, most liberal terms were offered by the Science and Art Department, Scholarships were established, and Free Studentships were also established; but during the whole time that the South Kensington School was in

existence I think we were only able to award a scholarship (and Mr. Merrifield can correct me if I am wrong) in two cases. The fact is that the class who were specially desired to present themselves did not come forward at all. A great many did come forward who had never been in any dockyard, and who had not had any experience before, with the intention, if they achieved some success at South Kensington, to do what they could in the profession afterwards; but it was intended and desired that persons who really had had some experience, and who knew one end of a ship from the other, who, for instance, had been in a yard and knew something of the use of their tools, should have presented themselves, but I think I may say, with scarcely an exception, not one single person answering that description presented himself at South Kensington. That will account for what Mr. John has properly informed us of, the comparative failure of the School. There are, however, one or two instances of persons who have had very considerable success. One especially is in my mind, who gained a scholarship, and then afterwards obtained what is called the fellowship of the School, who is now doing very well indeed. I believe he is now employed at Glasgow, in one of the eminent firms there. If you can get over that difficulty, and you can persuade gentlemen who are concerned in private shipbuilding that there is some advantage in scientific training, then you may attract the class of students that is required, but until you can do that (and I confess that during the whole time I was officially connected with South Kensington we found it a hopeless failure) I am afraid the complaint made by Mr. John in this Paper will still continue to be a complaint from year to year.

Mr. Henry Liggins (Associate): My Lord, I so thoroughly concur in the remarks that appear in this Paper that I rise to make a few observations on the subject. I think the weak point of the course of study at South Kensington by the class of persons who were to benefit by it was its being for so long a term as three years. It is not always the case that young lads can devote three years to study without the means of getting some pecuniary advantage for the time they devote, and I think Mr. John is quite right when he suggests that a shorter course should be adopted for a special class of students. I believe if that were done a large number would be likely to apply for the benefit which they would no doubt derive from the course of study in that noble Institution. I speak with some experience, because for a number of years I owned a small class of merchant ship which traded from London to the West Indies, but which do not come under the regulations and rules of the gigantic ocean steamers which we now so often hear of. But that is a very important and necessary class of vessel, and more numerous than the large ones, and I found from experience that it was exceedingly difficult in the best shipwrights' yards in London to get anything like scientific knowledge in connection with those ships, if any science was desired to be brought to bear upon them. The work that had to be done in the way of restoration and repair under Lloyd's surveyors was entirely done by rule of thumb, and it was rather sad to know that the work might have been more efficient if it had been guided by the practical results of well-known science. I observed during my father's time, before the apprenticeship system was abolished in connection with merchant ships, that the very best boys we ever received in our vessels were boys who had received their training at the Royal Naval School at Greenwich, and if that class of boy of that day came to us with more knowledge of seamanship and navigation than the same class of boy who had not had the advantage of the training at the School, I think we may argue that if in the scientific branches of shipbuilding and engineering we were to get the same class of boys, or a little higher class in social position, we should derive extra advantage. Therefore, this movement ought to be encouraged by this Institution, and might be taken up with advantage for consideration by the Government. I think there is a precedent for it which is just now before our minds. I had the good fortune at Kensington not long ago to attend a meeting on an educational subject, the chair being taken by His Grace the Duke of Argyle, that was for giving better instruction to ladies by Professors of King's College in London. Very much to the surprise of the ladies themselves, and I believe very much to the astonishment of the Professors, they found in a very few weeks they had 600 students on their lists. Now, if a large institution like King's College can depart from its usual *curriculum*, and receive students outside its course, I do not think it would be very difficult for the large establishment at Greenwich to take some course of a similar nature. I believe if they would do so in this case they would be rendering most valuable service to the great shipbuilding interests of this country.

Mr. Benjamin Martell (Member of Council): My Lord, I hope, before this Discussion is concluded, we shall hear some remarks from Mr. White, who must have given much thought to the question raised, and it must be the wish of everyone to have this Paper thoroughly discussed, as it is upon a very

important subject. The benefits of technical training in Naval Architecture have certainly not been taken advantage of by the mercantile marine like they have by the Royal Navy, and we know this has arisen principally on account of those very obstacles which Mr. John has pointed out. In the first place, it has been owing in great measure to the long term of three years being deemed an essential feature. A very great objection is felt by shipbuilders to sending their sons away from their yards for the whole of that term. The next point is, there is an impression they would be kept too exclusively to calculations which, though most intricate and instructive, would be useful chiefly for designing men-of-war and iron-clads, but would be of little comparative use to them in their profession as private shipbuilders after leaving the College. We have at Lloyd's Register had many enquiries as to the nature and fitness of the course of training at the Naval College for Private Students. We have endeavoured to give them as correct an opinion on this point as possible, but knowing as we did the requirements of many of those persons, I fear it was not always so favourable as we could have wished. If a short term for private students could be initiated such as Mr. John suggests, and if the difficulties of making the professional training suitable to persons studying for the mercantile service are not insuperable, I am sure such a change would do an immense amount of good. If we could only bring private students to take part in the studies of the Naval College in conjunction with the Admiralty students, good feeling and emulation would be awakened between them, which would do good to both services; and I have no doubt in my own mind that contact of this kind would promote a better understanding, and develope the training of both Admiralty and private students to a very great extent, and it would, I feel confident, soon be found there were large numbers of private students desirous of entering the College. Dr. Woolley was not quite right in his remarks that no practically-trained private student presented himself at South Kensington. I know a friend of mine, a shipbuilder on the East Coast, who sent his son there. He was brought up in his father's yard, and he understood thoroughly the practical part of shipbuilding before going to the School of Naval Architecture, and although of course he derived great advantage from that School, the result of his studies there was not nearly of so much benefit to him in his profession as it would have been had a course of instruction suitable to the mercantile marine such as that pointed out by Mr. John been imparted to him. I do hope that we shall soon see some of the suggestions made in Mr. John's Paper carried into practice at the Naval College, and if they can be adopted I am sure very great good will result therefrom to the mercantile marine of this country.

Mr. William Henry White (Member of Council): My Lord, first of all I desire to apologise for Dr. Hirst's absence to-day. I saw him this morning, and if he could have been here he would have spoken on this important subject; but there are now in progress College Examinations, and he cannot be here. This Paper I have read with the greatest interest, and read it perhaps with greater interest because it is a continuation of a Paper which I myself read at Glasgow, to which Mr. John has referred. I may say at the beginning, that Mr. John's suggestion as to the arrangement of a limited course of instruction, dealing with ordinary ship calculations, &c., has already been entertained. It was a matter of careful consideration about a year ago. I had very much to do with the proposal in its earlier stages, and Dr. Hirst most carefully considered the idea of arranging, if possible, for the addition to the College course, as now ordinarily carried out, of a more limited course, which could be taken up with less mathematical knowledge. It was found, however, and Dr. Hirst has since expressed the opinion to Mr. John that without an increase of the College staff this addition could not be made. It is important to remark one difference between the Royal Naval College and the School of Naval Architecture at South Kensington. I was trained at the latter place, and have the pleasure of still being connected with the College at Greenwich. I know the points in which they resemble, and I think I know the points in which they differ. It must be remembered that the Admiralty, in establishing the College at Greenwich, had principally in view the establishment of an Institution for Naval Education—that is to say, the education of the officers of the Navy, and it was seen that adjoined to that there might very well be—in a corner of the College, as it were,—one department which should form a continuation of the School of Naval Architecture so far as the Admiralty students were concerned. Dr. Woolley has said that the School of Naval Architecture, so far as private students were concerned, had been almost a failure. A number of private students had come; they had come either ill prepared, as I stated at Glasgow, mathematically, or else, as was the more common case, ill prepared professionally, or both. Some of them scarcely knew, as Dr. Woolley said, one end of the ship from the other when they came.

There seemed to be an idea that shipbuilding could be learnt at South Kensington. We had a splendid collection of models there, and endeavours were made to utilise those models, but it was found, as might have been anticipated, that even the hardest working students could not learn shipbuilding without going to a shipyard. Therefore, when the College at Greenwich was established, the Admiralty had before them a great scheme of naval education; they had also the fact that the training of private students at South Kensington had not proved to be a success. In starting the College at Greenwich it was natural that the training in naval architecture should be specially arranged for Admiralty students, but there was also a permissive clause for the admission of private students. The Free Studentships and Scholarships existing at South Kensington disappeared. Dr. Woolley was a member of that Committee, and no doubt he could tell the reason why. From that time to this only a single private English student has come into the College: he was a student of engineering; and not one single English student of naval architecture has ever joined since. Now those are the facts. The difference between South Kensington and Greenwich is, that the one was an Institution founded for instruction in marine engineering and naval architecture; at Greenwich this training forms only a department in a much larger Institution. The staff required for the larger Institution—the mathematical staff for instance—is utilised as far as may be in the higher training of the students of naval architecture and marine engineering. There are special instructors in addition, but as all the facts are set out in my Paper, which is published in the last volume of the Transactions, I need not enter upon them. It will be seen, I think, that there is a difference, and a very considerable difference, between South Kensington and the College; but I am glad to say that, although the College course has been arranged mainly for the benefit of Admiralty students, we have already in some small measure, and to the best of our ability, anticipated Mr. John's suggestions. We had one or two foreign students who came there as students of naval architecture, and who did not desire to go through the elaborate calculations for war ships, but who have been taught the ordinary calculations for merchant ships so far as they were capable of following them. But can that be carried out on a larger scale? Where we are dealing only with one or two, it may be practicable, and may be done with the same staff of instructors; but I quite agree with Dr. Hirst that it cannot be done on a large scale without addition to the staff. Shall such addition to the staff be made? Has there been any demand from the private trade that it shall be? Shall we frame beforehand an elaborate system of education? I think gentlemen here will agree that when the demand arises, then the question of the extension of the College staff may very well be entertained, and I think will be entertained. I am sure the feeling at the College is, that the more we can get the sympathy and support of the private trade the better it will be for the Institution in every way; and I for one, as I think I showed in my Paper read at Glasgow, earnestly long for such a time to come, because I cannot help thinking the pith of Mr. John's Paper lies in the suggestion that the College must concern itself primarily with the teaching of scientific principles, and with supplying the tools to the student for his future use. There is one thing more we have not yet insisted on, and that is any professional test for entering at the College; nor had we at South Kensington. I believe it existed on paper, but did not exist in fact.

Dr. Woolley: Because nobody presented himself, Mr. White. But at the College in the future it is no secret that there will be a professional test for examination; and we shall not let anybody deceive himself, even if he wishes to do so, by thinking that at the College he can learn shipbuilding. The shipyard is the place for that study; and I think that any one who has been through the course that Mr. John and myself followed, would find he had all his three years' work to do at the College in getting through the full course. The better one comes prepared the further he will go, and although there are plenty of men who do not accomplish the full course, yet we have to think of the fact that a knowledge of shipbuilding is really the substantial foundation on which all the applications of science, so far as they can be taught at the College, must rest. It should be distinctly understood, therefore, that there will be a professional test added to the mathematical test in the entrance examination; and I think I may go further and say that in connection with this very generous offer of Lloyd's Committee—which I am sure does them honour—there will be the same professional test insisted on before entrance. The candidates will not be mere forward schoolboys, who have got well into mathematics, but they will be expected to know something about work—men who could combine some amount of mathematical education with some amount of professional education. We do not teach shipbuilding at the College, although we have there still a magnificent collection of models used for instructional purposes; but I think any one who

has knowledge as a shipwright or engineer will agree that the shipyard or factory cannot be superseded by the most splendid and perfect educational system. Mr. John in his Paper has made special reference again and again to the desirability of visits to private shipyards. I quite agree with him, but who is to arrange that? Can the College authorities do it? I think not. I think it would be considered an attempt at interference by a Government Department with the rights of the subject. I have heard of Government Departments interfering in anything but a pleasant way with private shipbuilders and marine engineers. Will not the private shipbuilders come forward and make the offer to the College authorities that the students at the Naval College shall have the right of entry to their yards, and the engineers the same? We know at present such invitations are not given, and I can tell you an instance of private students having come to London who would have been shut out from all chance of getting practical knowledge had it not been for the generosity of the Admiralty in allowing them the fullest access to all the Royal dockyards and factories. Mr. John is quite right in saying that at South Kensington the private students went to the Royal dockyards. Why? Because they could not go to private yards. We sometimes had, as Mr. Merrifield knows, an invitation to visit some of the private yards on the Thames, just for a day's outing, but as to frequent attendances and inspection of work, I never heard of such an offer being made. I do hope the private shipbuilders will help us in that way, and give facilities which I thoroughly agree with Mr. John in thinking are very much needed. I may say that I think Lloyd's Committee with their great influence with private shipbuilders, and their warm interest in this matter of education, can help still more largely; and if the intelligent guidance which Mr. John speaks of could only be the intelligent guidance of a Lloyd's surveyor going to inspect the ships that are building and repairing, the students would be taken direct to the things which are most worth seeing. My experience in a shipyard is that you can walk about for many hours and miss the things most worth seeing; but if there is any one who can act as guide much more may be learnt in a shorter time. For what kind of men should the College training be most adapted? That is an important question arising out of this Paper. I think I may say that there are a large number of draughtsmen in the private dockyards of the country who do get the limited information which Mr. John thinks might so well be added to the College course, and to which I have not the least objection. I hope that is distinctly understood. The fact is, there are large numbers of draughtsmen in the private yards who can compete at the science and art examinations in naval architecture (which I wish were more supported by private shipbuilders in the different ports) with apprentices trained in the Royal dockyards, and win medals, although the examination is largely based on the practice of the Government yards. It is a fact worth noting that the shipyards and the mould-lofts themselves furnish considerable facilities for the training in these lower classes. I do not say that is all which is needed, but there are those facilities existing for the lower training. But where in England do facilities exist for the higher training outside the College? I know of none. Professor Rankine, at Glasgow, formerly did something of the kind, and there are still pupils of his at work in the profession who do him credit. I do not know whether Professor Thompson continues that class; I think he told me at Glasgow that he did not. It is only in the College, therefore, that this highest training can be got, and I say the men trained at the College are not men who should be exclusively employed in the ordinary work of the shipyard. I do not say they should exclude the lower class, but my distinct opinion is that in an Institution of the style of the College at Greenwich, with only limited appliances, the highest training should certainly not in any case be sacrificed to this training of a lower class. If the two can be associated no one will more heartily rejoice in that association than I shall.

The Right Hon. Sir JOHN HAY, C.B., M.P., Admiral (Vice-President): My Lord, Mr. White has answered one of the questions which I proposed to put to Mr. John on the subject of this most interesting Paper. When we Members of another House, the House of Commons, hear speakers say that an additional staff will be required for a particular purpose at the Royal Naval College, an Institution to which I have always wished well, and to which I am sure the House of Commons wishes well, and desires it shall have the facilities for teaching all that it can teach and ought to teach, and for which teaching there is a demand, I want to go a little further, and hear from Mr. John some information as to the demand for that additional teaching. We have heard that the College can give us good teaching; we have heard an additional staff is required, and we hear that there are no pupils. It would be very difficult to propose in the Assembly to which I have alluded that there should be an additional staff to teach when there are no pupils to be taught, and when there is no specific desire for

that particular teaching. The point has just been alluded to with reference to the fact that in the lower and more practical branches of the art of shipbuilding the private yards are not deficient, and that somehow or other they get information, or they are taught in some way in some places in the country, which, as far as I understand from Mr. White, are not acknowledged to exist now that we have lost Professor Rankine. I want to know how that is done. And now, in illustration of this subject, I want to call the attention of the Meeting to the fact that the other day great encouragement was given by one of the ancient City Companies, the Shipwrights' Company, who did me the honour to invite me to attend when the prizes were given for the best design, and, as I understood, the highest skill developed in the art of shipbuilding; and a gentleman who never had had the advantage of being at the College, or at South Kensington—a gentleman whom I hardly know by sight, except that we all saw him receive his prizes one after another with great interest. This gentleman's name was Mr. Mackrow, and I am told he never had the advantage, if it be an advantage, of being at the Naval College, and he had not the advantage of being trained by Professor Rankine. If that be so—if a gentleman can appear on a great public occasion like that, when eminence and distinction only can have obtained such rewards, how and where is that instruction obtained in the private trade? If that be so, how are you to persuade Parliament that it is necessary to add the additional staff and the additional strength to the Naval College, which at present, although capable of giving that instruction, cannot persuade persons that they ought to come there to be educated? I thought that was a point which Mr. John in his reply might very fairly attend to. There were other gentlemen besides Mr. Mackrow who obtained commendation and prizes, but of their previous history I know nothing; only I did happen to remember the name of that gentleman. I made some enquiry on the subject, very insufficient enquiry, but so far as I could learn, he had not had the advantage of instruction which it is said would have given him the highest education possible; and yet I suppose that the rewards were given to him, not only for draughtsmanlike qualifications, but for the higher branches of calculations and of knowledge which we desire. I will not detain the Meeting longer, because I can give them no information upon this particular subject, but I should be glad to hear from Mr. John an answer to my enquiry, and I think it would be of advantage if it were known where the private trade got the information for their best designers, and whether there is really any demand and necessity for this additional staff, and for other means of inducing pupils to attend the lectures and receive the instruction which is given at the Royal Naval College.

Sir Robert Spencer Robinson, K.C.B., F.R.S., Admiral (Vice-President): Before Mr. John replies to the questions which my worthy friend Sir John Hay has put to him, I should like to make one or two observations, which coming from a person not in any way professionally connected with naval architecture may perhaps assist the gentlemen who are connected with shipbuilding and ship designing in following out the statements made by Mr. John, and so ably commented on by Mr. White. The practical thing that I have been struck with in listening to both those gentlemen is the difficulty there appears to be to find young men with some sort of qualification—knowing one end of a ship from the other—and having some outline of scientific knowledge, presenting themselves to receive that instruction which is so valuable, and which is so ably given at the Royal Naval College. I think the cause of that unwillingness was ably explained by Mr. White, who stated exactly what all of us who have considered the subject at all must know rather to be the fact than otherwise. It is this: there is no demand by the persons who construct ships, by the designers of merchant ships and the merchant traders generally, or there is not a sufficient demand for able designers and for mathematical instructors. The moment that demand arises, so far from finding that students do not present themselves to receive the instruction which is necessary, I should think, judging by all other experiences, there would be found immediately a very great increase in the number of students who ask for that instruction, and who require that teaching. I know my friend Sir John Hay does not in the least mean to cast any doubt upon the value of instruction in every branch of knowledge that can possibly be acquired by man. It is perfectly true, as he has no doubt convinced the Meeting by what he has said, that now and then there comes a person gifted with superior acquirements and powers who, apparently without teaching, or you can hardly tell where his instruction has been got from—perhaps from his own studious labour—comes and carries off prizes and wins distinction, while those who have received all the advantages of a most excellent education and training, fail. But surely those cases must in every instance be considered the exception? The rule of life must be a general one—that is, you can only reckon upon finding men gifted with average abilities,

and it is with men of that stamp that superior education and training will have the greatest possible chance of developing whatever talent they may possess, and bring success within their reach. One of the suggestions of Mr. White struck me particularly. It is this. Will those who are connected with large private establishments give facilities and advantages to young men who belong to them, or to those who do not, to see the whole of their working, and to learn practically many things that can only be, as we well know, taught in a shipyard? I was going to give an example in my own case of how it would operate. A great many years ago—I am sorry to say, in 1838—it so happened that I received my promotion as a Commander in the Navy, and the great want I felt was this: I had the practical training that most sailors had, and I think knew as much about seamanship and handling a ship as men of my age could have known, but I found myself deplorably ignorant of the subject of the steam engine and steam machinery as applied to ships. I went to several places—I will not name them. I said, "I am a naval officer—an ignorant naval officer; I want instruction; I want liberty to go through your yard, see your works, and you can rely upon it that I will make no bad use of the knowledge you are kind enough to afford me the opportunity of gaining. I shall apply it to the next class of vessel that I may have the honour to command." I will not tell you how many refusals I got, or tell you all the places to which I applied; but I will tell you where I was received. I was received with open arms at Glasgow, with that kindness and hospitality which I think has always distinguished the scientific bodies of Glasgow, and I was permitted by Mr. Robert Napier, who I regret to say is now no more, to go into his yard, to put on a fustian jacket and a pair of canvas trousers, and go through the whole of the work that any one of his apprentices would have gone through. I think the advantage I derived from the knowledge imparted to me by Mr. Napier is an advantage which many of the young men alluded to by Mr. White and Mr. John would find of enormous benefit to them and to the profession generally. If some of the great mercantile establishments connected with shipbuilders would give the same encouragement to people to acquire knowledge as was given to me by Mr. Robert Napier at Glasgow it would do a great deal of good, and prepare the way for young men to acquire knowledge in the higher branches of their profession. I have always been particularly grateful for that, and whatever little success I have had in life I attribute to the consideration, kindness and teaching which I received there.

Mr. William Denny (Member of Council): Perhaps, my Lord, you will permit me a word upon this Paper as a private shipbuilder. Before speaking upon it, however, I would only ask, with regard to what Sir John Hay has said, whether with those models and plans which were submitted for competition the calculations in full, corresponding to them, and in perfect detail, were also required? Was this test really brought to bear on the competition?

Mr. Benjamin Martell (Member of Council): No.

Mr. Denny: With regard to what Mr. John has said, I think on the part of merchant shipbuilders there are due most hearty thanks to the Government for the opportunities they have put before them. I quite acknowledge that Dr. Woolley has a just plea against us in the indifference that up to date has been shown to a higher training. I acknowledge it, and am sincerely ashamed of it, but I do not believe you will find that indifference lasting. Under the efforts of this Institution, and from the opportunities of discussion it has afforded there has arisen a desire for a higher training in naval architecture, and the benefits certain to be derived from it. If Dr. Woolley will only give us a chance of repentance he will find that he will have repentant children returning to him. Concerning the teaching Mr. John advocates, Mr. White has mentioned that the teaching to a great extent of the kind he asked for was already given in the private yards, and I am able to assure you from my knowledge of them that this is the case. In many private yards it is a common thing for the calculations of strains of ships to be worked out, for the stability of ships to be investigated, for ships to be inclined, and for the longitudinal metacentre to be used for calculations of changes of trim, and for those changes of trim to be carefully studied in connection with the performance of a ship, on a long voyage, so that her consumption of coal may not throw her propeller out of the water into the air. I do not think in the mercantile marine there is so great a want of teaching of the kind referred to except perhaps in a class of yards where there is a total indifference to anything but the manufacture of ships as one would manufacture shoes. There arises of course the difficulty that many shipbuilders really anxious to improve their sons may say they may not have the means of doing so in their own yards, and of course cannot exactly knock at every yard where such exists and ask their sons to be taken into it. On this account there is a certain reasonable plea for what Mr. John asks. Still I wish to point out that a training up to

the extent which he asks of the Naval College already exists in many private yards. But while that knowledge exists it is insufficient, and short of what a naval architect should have. I do not think the standard set up by the Royal School of Naval Architecture is for its own purposes too high, nor one bit too high for the mercantile marine, if they only knew their true interests. There is another matter upon which I desire to make a remark—that mercantile naval architects entering the Royal Naval College should be taught naval architecture in its practice and in its practical design from the iron-clads. I would differ with him upon this point; because, although iron-clad construction, even in its minor details, cannot be forced into mercantile shipbuilding, still there are many things worked out to their full completion which can be tested in an iron-clad but which cannot possibly be tested in a mercantile ship. To confirm this opinion attention need only be drawn to an important question which I believe the mercantile marine will yet be called upon to study, if passengers will only demand it, and that is the behaviour of ships at sea in rolling. There is no possibility in the mercantile marine of getting observations made on the rolling of ships at sea. The ship constructing in your yard, so far as accurate information can be obtained about her behaviour at sea will remain a dead letter to you all her natural life, indeed it is only in the case of iron-clads that predictions regarding rolling can be verified. It is unquestionably necessary in the higher branches of naval architecture that one should study, not only the form of ship he intends constructing in his future life, but also that kind of ship which will experimentally show him the full and combined results of the highest calculations. I think this Meeting will agree with me that even on many other points it is only the Government ships which can afford such opportunities fully. Permit me now to touch on a very important point, more important than perhaps appears at first sight: that is the present South Kensington examinations in naval architecture—those examinations which are so admirably conducted under Mr. Baskcomb. Now, I do not say one word against Mr. Baskcomb's conduct of those examinations, for I believe up to date they have been as perfect as possible for the ground taken up. I would however suggest for his consideration some recommendations in the way of an enlarged usefulness. Those examinations at present run through three grades, which are almost all concerned with laying off; indeed it is only in the final grade that the examination is concerned with even such a simple matter of calculation as displacement. What I would suggest is this. Might there not be added to those examinations a little more perhaps about construction and strains, and about workmanship in iron? I think if that were so it would be of considerable advantage, and would tend greatly to improve the skill of our private yards. When I tell you that in the small town from which I come, which has only a population of 13,000 inhabitants, there are twenty-five students of naval architecture working in a class, and with an average attendance of about twenty every night, you have proof that there is no want of appreciation of such education when it is brought fairly within reach of the people. Many of the students are simply workmen who are desirous of improving themselves. Indeed I know of one poor fellow who has attended this class six years, only passed the preliminary each year, and yet is quite contented. I think if this work of the South Kensington Department were taken notice of by this Institution, and were fostered by it as it has fostered and I hope will continue to foster the Royal School of Naval Architecture, very great good would ensue. Here we have at our hand a vast organisation already working beneficially: we could easily convert it into an engine of great power, and of utility. It is already appreciated, and there is no reason to say people do not call for, and do not benefit by it. Should we not therefore turn our attention to it also? I do not say the Royal Naval College might not be improved by some of the suggestions of Mr. John—perhaps it might. I would however ask Mr. John also to consider this very important question of the South Kensington examinations; and I would ask this Institution to give the weight of its influence, and you, my Lord, to give the weight of your influence, which you have so often used for the benefit of the mercantile marine of this country, to the purpose of improving this organisation which we have already in action, and of converting it into one of even greater usefulness.

Mr. Charles W. Merrifield, F.R.S. (Associate Member of Council): My Lord, I did not intend to speak on this Paper, but I think there are one or two more points on which the Meeting would be glad to hear a few words from me. One is this. It was no doubt true, as Dr. Woolley says, that we had but a very small proportion of private students who came to us at South Kensington sufficiently well trained either to obtain free scholarships or exhibitions. I think the causes of that are not far to seek, and, as has been already stated, the chief cause was the want of appreciation of the Institution in the private trade generally. In that respect I think the matter rests entirely in their own hands, and they

will do well to look to their own efforts to bring about such professional education as they really feel and appreciate the necessity of, rather than to depend on any very efficient support from the Admiralty. The Admiralty will give them the means of getting this education, if they are disposed to avail themselves of it, but the Admiralty is, I think, an Institution which can give them nothing more. Certainly the Admiralty was never wanting in liberality in the matter of instruction; it has in the noblest manner given the fullest facilities for education to the private trade; but something more is wanting before you can attract students from the trade of which the education has been, I will not say low, because I suppose few persons, taking them on the whole, have had a better professional education than the shipbuilders in the private trade as well as in the Admiralty, but still they have not altogether appreciated the full value of higher education in the way I should like to have seen it done; and to get that appreciated it is not sufficient to be willing to afford them the means of education, but you must go out into the highways and byeways and persuade them to come for it. Now the Admiralty is emphatically a body that could do that far less efficiently than South Kensington was able to do it. We failed there because we were not appreciated by the private trade. We were beginning to be appreciated because it was our business to become so; we had an individual profit in accommodating ourselves to the private trade. Now, the Admiralty have no such object; on the contrary, they cannot afford to go out of their own way, and if they adapt themselves to the private trade, they do it at considerable inconvenience to themselves; an inconvenience which never fails to be felt in the efforts that many actually make to secure it. You have been told, and rightly told, by Dr. Hirst that he will require a fresh staff. It is impossible that you should take up the half educated students who may come, if you go out into the highways and byeways to collect them, with the same staff which is already fully taken up with the higher education of naval officers. In my own school I was obliged to have recourse to private study, besides giving a good deal of extra time of my own; but I had an object in it, for I had a share of the fees of the private students, which directly told on my income. I found that was not sufficient, and that I could not afford to give all the necessary time to it, and I was obliged to compel the men to employ private tutors to qualify themselves for the course of instruction which they were to receive. I think we must not hope too much from the Admiralty in that way; but I think the whole thing must come from the private trade. If the private shipbuilders are really willing and desirous to make sacrifices to get this education, then they can get it, but they must make some sacrifices to do so. They must send their own children there, and they must give facilities for the children of others to enter their yards. There is a great difficulty about the latter point which has not been mentioned here, but I am not willing to let it slip. I found very definitely when I began to look for private students, that I came into competition with the apprenticeship system, and that it was particularly difficult for the shipowners to assist me either by sending me their own children or the children of other parents, without doing it at a personal sacrifice of some portion of the fees which they got from apprentices. It is not very likely under those circumstances that they would ever open their yards to private students. I fancy that that will still be felt. With regard to the Admiralty, one point that will be strongly felt in relying upon the Admiralty for assistance is, as I have already stated, that they would have to go out of their way to adapt themselves to the necessities of private shipowners; but while in most other educational institutions, such as the Universities are, their primary business is to adapt themselves to the necessities of the students who come there, the Admiralty are under no such obligations, and have no such interest. On the contrary, the habits of the service are all opposed to their doing so, therefore we must not depend upon them too much to assist the private trade. At the same time, I think shipowners and shipbuilders have the matter to a very great extent in their own hands; because, if they really feel the want of these men, and are, moreover, prepared to give them employment when they have obtained the education, then I think they will have no difficulty in getting it for them, either through the Admiralty, or, failing that, in some other way or other through one of the great Colleges or Universities.

Mr. John R. Ravenhill (Member of Council): My Lord, I am going to ask if I may put a question. It is this: Sir Spencer Robinson made use of the term "average abilities." Now I should like to ask Mr. White whether he considers the standard of examination of admission to Greenwich at the present time is one that lads of average abilities at their respective ages ought to pass? There is a feeling outside that the standard required there is somewhat high, and Mr. White knows whom I refer to when I mention that a very high and well-known Admiralty official did not send his son to Greenwich, but sent him to Owens College at Manchester. I am sure any information that Mr. White will give the

Meeting on this point will be valuable and interesting. There is one other point which Mr. Merrifield touched upon, and which Mr. White alluded to, and that is, asking the firms on the Thames to allow these students to visit their yards. It does entrench on the apprenticeship fee. A friend of mine was asked only a few days since 600 guineas for a lad to be in one of our oldest London marine engine factories for a term of five years. It is a very difficult question—one that Mr. White, I think, is fully justified in bringing under our notice; but it appears to me to be one beset with very grave difficulties.

Mr. WHITE: I was about to answer Mr. Ravenhill's question. I omitted to state that as the result of the Paper read in Glasgow—I hope it is the result of that—several sons of shipbuilders are already preparing for an attempt to pass their entrance examination, and I know of other firms, where the heads of the firms have not sons of an age to come, who are simply looking about for suitable men to send—men whom it will be to their interest afterwards to employ, having paid their fees for education. As to the entrance examination, I think a great deal depends on preparation; but I may say that, in addition to the professional test, it is contemplated to somewhat lower the mathematical standard.

The PRESIDENT: Gentlemen, I cannot call upon Mr. John to make his reply upon this subject without first venturing to offer a very few observations on this extremely interesting Paper and this interesting Discussion, which appears to me to lie at the very root of the main objects for which this Institution exists, and for which it has for the last nineteen years worked so hard. I hope, therefore, that the Meeting will not blame me for having allowed this Discussion to slightly exceed the limits of time properly prescribed. I must, in the first place, express my very great regret that Dr. Hirst is not here to-day. I think, from the turn which this Discussion has taken, that the experience of Dr. Hirst would have enabled him to add in a very valuable manner to the Discussion we have heard. I must also express my great satisfaction that the able and practical Paper we have heard from Mr. John has followed so properly and so appositely, as I venture to think, on the Paper which we have heard from Mr. White at the Meeting at Glasgow. I was very much struck at the time, and if I remember right I think I said so, by Mr. White's Paper, and I was very much in hopes that that Paper would lead to some practical good effects. I must say I think it has led to a practical good effect in being the parent, if I may so express myself, of the Paper we have now heard from Mr. John, and which has led to this very full Discussion which we have now heard. Gentlemen, it is true, as has been remarked I think by Mr. White, that the Naval College, as it stands at Greenwich, was established mainly and primarily for the training of officers in those professional respects in which they previously followed their training at the College at Portsmouth, and you must all remember it was considered a very doubtful question whether the transfer from Portsmouth to Greenwich was on the whole a wise step. I am not sure whether I was not of those one who doubted it. I think, therefore, I ought rather the more to say that I think the advantage of good masters, and good teaching, and having friends in London, which is gained at Greenwich, does compensate for any disadvantages which have followed upon the learning of Portsmouth. Gentlemen, the question then really is, whether or not it is not desirable that upon the Naval College mainly and primarily established for the training of officers, there should not be founded an efficient and effectual School of Naval Architecture. The School of Naval Architecture to a certain extent you have got—a school of naval architecture which trains the naval architect mainly for the purposes of the Navy; but I think the general tendency of this Discussion has been to show that that School of Naval Architecture so established at Greenwich has entirely failed up to the present time to afford any of those facilities and those aids for the private trade of shipbuilding which it is so desirable for the most obvious national purposes that we should obtain. Then the question of course comes before us, how are we to gain it? We have heard now, from probably some of the most competent men in England on this subject who have addressed us to day, how strong is the feeling, how strong is the necessity. I am one of those who believe that when in this country the public mind is formed upon the necessity of any great purpose or any great reform, the means of carrying it out are sure to follow, and I hope that will be the case in this instance; and I have, as one step towards it, very great pleasure in finding myself at liberty to read to this Meeting a memorandum which was placed in my hands yesterday. It is, I suppose, very hastily written, for, to speak in common terms of it, it has neither head nor tail, and to whom it is addressed I do not exactly know; but it was put into my hands by so high an authority that I cannot for a moment doubt the real weight of the paper. It was given to me by Mr. Barnes. Mr. Barnes wished me to speak to him about it, but it was at a moment when it was my duty to come into this chair, and

I had not time to speak to him, and did not know what the paper was about. I am very sorry it was not sent to me in a form which would enable me better to understand it, and communicate with the gentleman who signed it. It is this:—"You will be pleased to hear that the Board of Admiralty have intimated "that a limited number of Free-Studentships will be offered annually to private students in naval "architecture and marine engineering at the Royal Naval College at Greenwich, who, having passed "the usual Entrance Examination, pass satisfactorily a further Examination in mathematics, chemistry, "physics, and practical shipbuilding or marine engineering. These Free-Studentships will be held for "three Sessions if the ordinary College Examinations at the end of each Session be passed satisfactorily. "In addition, to the Candidate who comes out first in order of merit, will be awarded a Scholarship of "£50 a year, also tenable for three Sessions if the College Examinations at the end of each Session are "passed satisfactorily. These arrangements will take effect next Session." I have read you the whole of this paper, and told you the exact circumstances under which I got possession of it. It was given to me, as I tell you, by Mr. Barnes, and I believe Mr. Woolley will support me when I say that Mr. Barnes stated it came from Sir Massey Lopez, one of the Lords of the Admiralty. I am sorry it did not come in a form which would have enabled me to make a more formal announcement; but I am led to believe from the way I got it, that I am not misleading you by reading it to you, and stating my belief and opinion that this is the intention of the Admiralty. If so, I think every one here will admit that the Admiralty are entitled to our gratitude, and we are bound to make a full acknowledgment of such an important step in the right direction. Here we have something on which I hope and trust there may be founded that which I think all who have spoken on this subject concur in feeling to be most imperatively necessary for the best national interests of this country—that the private trade should have the advantage of good and efficient training in the science of naval architecture. Such, Gentlemen, are the few remarks I have desired to make. I must repeat with what pleasure I have listened to this Discussion, and I hope it will bear fruit which will enable us all hereafter to look back with satisfaction on what has occurred to-day.

Mr. William John (Member of Council): My Lord, I feel much pleasure at the interesting Discussion my Paper has given rise to, and I feel that I am amply rewarded for any trouble in preparing the Paper by finding that it has brought about such a Discussion. There are but one or two points I desire to refer to. In the first place I wish it to be distinctly understood that it is the furthest from my thoughts to want to diminish or rather to lower in any way the standard of training at the Naval College. I wish, on the contrary, to see the scientific training given there kept as high as possible. But the broad fact I hope to bring out is this—that while knowing, as I do, the value of a high training of the kind I am now referring to, I feel that the private shipbuilders of the country do not, or have not up to the present time, shown that they sufficiently appreciate it to give students the necessary preliminary training to enable them to go through the whole course of study at the College successfully. I mentioned in my Paper—I do not think it was observed—that I rather referred to a shorter course of study for private students at the College as being desirable, if not permanently, at least as a temporary expedient. I would put it in this way. There is no doubt that the College does not at the present time draw from the mercantile marine that support and that supply of private students which it has a right to expect, and I have found there is a feeling of this kind prevailing. To take three years out of a student's life to go to the College, to take him away, in fact, from the practical business of the shipbuilding yards for so long a period is felt to be a great sacrifice of time and experience, and it is not felt, or at least as yet it is not realised, that he will get at the College a sufficient return in useful professional knowledge for what he thus loses. I think, however, if private students did go from the shipbuilding yards to the College even for a short and possibly incomplete course of study, that they would learn to appreciate the higher course of study, and that in this way we should overcome the scepticism that exists and bring about that confidence which is before all things necessary to render the College useful to the mercantile marine. I fear I am not making the matter so clear as I could wish. Sir John Hay mentioned another matter connected with the College training as it at present exists, and Mr. Denny also referred to it, *viz.*, that means of imparting a good training already exists in the private shipbuilding yards, and Sir John Hay referred, as an illustration, to the recent Exhibition by the Shipwrights' Company at the Fishmongers' Hall. I quite admit that there is a large amount of valuable training to be got in the private shipbuilding yards at present, and we know perfectly well that all our very fine merchant vessels are designed and have been designed for the most part by men who have not had a scientific training

such as the Naval College provides. It is quite possible, of course, without going to the Naval College, to get up to a high pitch of perfection in naval design, and to obtain a great mastery over the principal questions connected with it, but as I take it, the advantage of an early training at the Naval College is this—that you are able to get at an extensive knowledge of the subject in less time—you have to spend a greater number of years in acquiring that knowledge in after life, which might be imparted at the College in a comparatively short time and more completely. Mr. Denny referred to the great advantage afforded at the College of being able to go into the complications and details of the construction and design of war ships. I quite admit that there is a great advantage in many ways derived from that; but it must not be forgotten there are also important questions in connection with the mercantile marine, as I tried to point out in my Paper, in the vast complications arising out of the numbers and types of vessels and their stowage and uses, which are not so fully treated there, and if we could show private students that at the College they could get in three years, or less if possible, a grasp of the general features of these types and descriptions of merchant ships, and of the whole mercantile marine, the College training would have a great attraction for them. What I want to see brought about is that the College should acquire a greater attraction for private students than it has hitherto possessed, greater than even Scholarships alone can give it. There are many who wish to go to the College to whom the £50 Scholarship is perhaps of little importance. The £50 Scholarship would not attract them there; but if they could be sure of getting a better knowledge of their profession as mercantile shipbuilders and designers there than they could get anywhere else, then whether there were Scholarships or no Scholarships, they would go there, and the College would not find a lack of eligible students from the mercantile marine. There remains the question of whether the College could even temporarily put forward a scheme for a somewhat shorter and more elementary course of instruction for the private students. That I feel to be one of the difficulties in this matter. I think it is most desirable, if it could be done, because young men, draughtsmen, from some of the best yards in the country, though they have acquired the knowledge mentioned in my Paper, the method by which to calculate metacentres, and weights, and various things, yet desire to go to the College to extend their knowledge beyond what they feel they can get in their own yard; but if they cannot do so without going for the full three years' course, and going in addition through a preparatory course of mathematical instruction, they simply have to give it up. If by any means some such scheme could be adopted even temporarily, until say private shipbuilders more fully appreciated the value of the College training, it would be a great boon to many. I may mention that I was encouraged rather to hope that a step in this direction might be practicable, because, when I look at the College I see that there are various classes there receiving different degrees of training. It is not as if there were only just one standard of teaching and one class there. There are many classes among the naval officers and among the engineers varying in mathematical training from the elementary branches to the highest. There are engineers there who go for twelve months. Out of those are picked others who go on for a higher course of education, so that it seemed to me that the College might, perhaps, be made equally elastic for naval architects, and that it might embrace an elementary as well as a higher course of instruction for them. Mr. White put the matter in this way, "Here is the College; there has been no desire yet shown by the mercantile marine to make use of the College, therefore we have not made special arrangements for the training of private students; but as soon as there is such a desire shown, then it can be met." This argument of course leads to a dead lock. Without special inducements and arrangements for their special instruction, private students do not seek the College training; and until they do seek training at the College, the College does not offer the necessary inducements. I think that this Discussion will tend as much as anything to bring about a better understanding, and that we shall soon see both the inducement offered and the desire to profit by it exhibited to a far greater extent than has hitherto been the case.

ON THE ADVANTAGES OF INCREASED BREADTH AND LESS DEPTH OF CARGO-CARRYING STEAMERS, AND THEIR COMMERCIAL SUCCESS.

By John Young Short, Esq., Member.

[Read at the Nineteenth Session of the Institution of Naval Architects, 12th April, 1878; the Right Hon. Lord Hampton, G.C.B., D.C.L., President, in the Chair.]

My object in reading this Paper is to deal with the proportions of breadth and depth of steamers, constructed for our Mercantile Marine. I do not desire to treat the question from a scientific standpoint, but rather to draw the attention of the Members of this Institution and shipowners generally to the advantages gained by increased breadth and less depth of cargo-carrying steamers.

In the early part of last year my attention was particularly directed to the proportions of three-decked steamers,—and after considerable opposition to the suggestions, principally from steam shipowners, I succeeded in inducing one of our German customers to adopt greater breadth and less depth. Since then it will be found by a reference to Lloyd's that it has become general among our local steam shipowners to build steamers of greater breadth for the general cargo trades. I am confident they will still be increased in breadth, and shortly we shall find three-decked steamers of similar proportions to those which I shall lay before you.

Before dealing with the advantages to be gained by increased breadth and less depth, I wish to show how a great number of our local steam shipowners have drifted into the proportions of breadth and depth of the majority of our present three-decked steamers.

Firstly. A few years ago a large number of the steamers built on the North-east Coast were of the long full poop type, of breadth and depth as 32 feet is to 18 feet. The building of this description of vessel is comparatively speaking a thing of the past, for as soon as the new Shipping Bill came into operation, compelling all vessels to be marked with a load line from the main deck, they were found to be placed at a great disadvantage, and were superseded by—

Secondly. The spar-decked steamer, which, as being built for carrying dead-weight cargoes, is now also a thing of the past. This type of vessel meant little more than decking over what was called the "well" in the former steamer (*i.e.*, the space from the fore-end of the poop to the after-end of the top-gallant forecastle was covered in with a deck running fore and aft), thereby making the depth 24 feet 6 inches, with no corresponding increase in breadth. The shipowner believed at the time he thus secured a much larger dead-weight carrying steamer, and got a greater freeboard, but the Registrars of Classification soon found it necessary to interfere with the loading of such vessels in consequence of such construction. The difficulty was met by the

substitution of the three-decked steamer, which I now describe. The proportions of breadth and depth are practically the same as the spar-decked steamer; lately they have been increased a little in breadth, and at present we find the majority of them building on the North-east Coast in breadth and depth as 34 feet is to 24 feet 6 inches. The advantage gained by the little increase of breadth has been, however, more than counterbalanced by the erections which have been added in most cases on the upper deck, such as full poop, long bridge-house amidships, and top-gallant forecastle. There can certainly be no objection to these so placed, provided the breadth is increased or depth reduced to bear them safely. Steamers of the proportions of breadth and depth as 34 feet and 24 feet 6 inches, with erections such as I have named on the upper deck, are found to be exceedingly tender, and I cannot but believe are dangerous at sea; therefore to give stability to such steamers it has frequently come under my observation that owners, with a view of getting the cargo well down into the hold, have dispensed with the double bottom for water ballast.

I trust I have thus pointed out with sufficient clearness the manner in which I think owners have drifted into the proportions of breadth and depth of the majority of the present three-decked cargo steamers, and their disadvantages; and I hope I shall be able to lay before you with equal clearness the benefits of increased breadth and less depth of such steamers. The proportions I suggest are as 40 feet is to 21 feet 6 inches (on the two-decked principle) thereby increasing the breadth 6 feet and reducing the depth 3 feet. That these proportions will be advantageous is, I submit, apparent.

Firstly. Because the increased breadth will give stability and enable such vessels to be fitted with a double bottom, all fore and aft, a principle which I think should be generally adopted, as the benefits of such an arrangement have been fully proved on many occasions. The double bottom of steamers, when built to Lloyd's requirements, is of sufficient strength to keep them afloat should they strike the ground or a wreck, thus enabling them to get to a port with safety and thereby saving much life and property. The increased quantity of water-ballast will immerse them sufficiently to make their passages when changing ports without taking in and discharging material as ballast, with consequent saving of time and expense. This point (the detention and expense) I need not enter into, as it was so fully and ably dealt with by Mr. Martell in his Paper on "Water Ballast" last Session.

The tank top of these steamers when loaded with heavy dead-weight cargoes will form a platform and raise the cargo sufficiently to make the steamer sea-kindly, and this may be necessary with some cargoes on account of the increased breadth. Then again there are some advantages to be gained by having a double bottom fitted fore and aft, among which I may mention that it gives additional strength; and by division into separate compartments steamers may be trimmed to suit any cargo.

A plan my firm have adopted, in all cases where water ballast is fitted under engines and boilers, is to carry a water-tight division fore and aft, with separate filling and pumping arrangements, so that in the event of the vessel taking a list by loading or shifting of cargo, she can be readily righted again by filling the light side, and I submit if this system of fore-and-aft division of tanks was to be generally adopted it would be found to add greatly to the stability and safety of the vessels.

Secondly. The increased breadth will enable the steamers to carry safely the erections on the upper-deck which owners desire and are now adopting, such as full poop aft, long bridge-house amidships and top-gallant forecastle. The whole of the

crew are thus housed above deck, leaving the entire holds clear for stowage of light cargoes.

Thirdly. Another benefit to be gained by increasing the breadth of our present cargo steamers from 34 feet to 40 feet, and depth reduced from 24 feet 6 inches to 21 feet 6 inches, will be to leave these steamers of about the same tonnage, and they will carry somewhat near the same cargo; but the broader steamer will carry her cargo on at least 2 feet less draught of water than the present type. Her owner will thus be able to send her to almost any port with safety, and without first having to discharge part cargo into lighters to enable her to enter, which is often the case with the present three-decked steamers.

The advantage of a steamer of about the same tonnage, carrying about the same cargo, with at least 2 feet less draught of water, independent of double bottom fitted fore and aft, and the erections on upper deck which I referred to previously, cannot but strike shipowners, builders, and underwriters as the best type of boat for our general cargo trades.

The prevailing idea among our local steam shipowners is that the increased breadth will impede the speed of the vessel, but this is found not to be the case, as the draught of water being naturally reduced, this makes the displacement equal. Some owners also think that steamers of the proportions I suggest, on account of (what they call) great beam, will prove laboursome and unmanageable at sea when loaded. I fully admit that to increase breadth to an extreme will have a tendency to make them laboursome, but the dimensions I suggest are not extreme, far from it; they are in the same proportion as we are adopting in our smaller steamers, which are principally of breadth and depth as 30 feet is to 16 feet, and such have proved to answer admirably. A steamer which I referred to in the beginning of this Paper, built last year by my firm, although not quite up to the breadth I suggest, yet approaching near it, being 36 feet broad and 21 feet deep, is steaming as fast as any vessel of similar carrying capacity and propelling power. The account we have from the Captain of this vessel is assuring, and I will read you one or two extracts from his letters to his owners; but before doing so I will give you the particulars of the steamer, the model of which I have no doubt many of you saw at the Shipwrights Company's Exhibition of Models in Fishmongers' Hall last May:—

	Ft.	Ins.	
Length	260	0	
Breadth	36	0	
Depth	21	0	to top of floors.

Tonnage under deck 1,508.

She has a short full poop, long bridge-house amidships, and top-gallant forecastle.

About the beginning of November last she left the Tyne with 2,350 tons of coal on board, on a mean draught of about 19 feet. The Captain writes from Alexandria:—"We arrived here safe yesterday. From the Tyne to the latitude of Lisbon we had "very bad weather, but have made a very good passage, and in general the ship proves "a success, and is a 'duck' in the water in bad weather."

In another letter, dated January this year, he writes from Suez:—"We arrived "here all well, and had a very good passage, but strong winds and a very high sea; "but the ship did well: she always ran 9 knots, although the coals were bad and only

"able to produce 60 pounds steam; but for that we would have been here a day or "two sooner."

The Captain was not in favour of breadth, and frequently remarked to his owners before sailing that he was afraid his vessel would be laboursome. The above extracts clearly show that the steamer behaved very differently to what he anticipated.

I may state that my firm are at present building two smaller steamers of the dimensions of 18 feet deep to 35 feet broad, but with a long raised quarter-deck, bridge-house amidships, and top-gallant forecastle. These dimensions, it will be seen, are quite equal to the proportion of breadth and depth to those I suggest in place of the present three-decked steamer, *viz.*, 40 feet beam and 21 feet 6 inches deep.

The dimensions and types of the steamers I have referred to will be better understood by reference to the following Table:—

	Full Poop.		Spar-decked.		Three-decked.		Proportions suggested.	
	Feet.	Inches.	Feet.	Inches.	Feet.	Inches.	Feet.	Inches.
Length	240	...	240	...	260	...	260	...
Breadth	32	...	32	...	34	...	40	...
Depth	18	...	24	6	24	6	21	6

In conclusion, I trust the few suggestions I have thrown out may not have been uninteresting: and although the proportions mentioned may not meet with general approval, a discussion on this matter may enable us to arrive before long at the best proportions for our cargo-carrying steamers.

ON A NEW PRINCIPLE OF CONSTRUCTION FOR WAR AND MERCHANT VESSELS, AND OTHER IRON STRUCTURES.

By T. R. Oswald, Esq., Member.

[Read at the Nineteenth Session of the Institution of Naval Architects, 12th April, 1878; the Right Hon. Lord Hampton, G.C.B., D.C.L., President, in the Chair.]

I think it will be admitted by every one conversant with the present structure of vessels, that a very large per-centage of the material employed is not brought into useful and effective work. For instance, a ship's frames, floors, beams, keelsons, and stringers are in themselves weak and inefficiently connected, until secured by the shell plating; this connection again is an imperfect one, being merely an attachment of a rivet every 5 or 8 inches vertically, and from 20 to 24 inches horizontally; and when it is borne in mind that in the framework, floors, stringers, beams and keelsons, fully three-fifths of the material employed in the construction of the vessel is contained, it will, I think, readily be admitted that a large per-centage of the material does not come into useful and effective work.

These remarks apply more forcibly when we consider the mode of construction of our ships of war. We have here to deal with a large mass of material used for defensive purposes; which material, with regard to the constructive power of the vessel, is not in any way utilized, but is a source of weakness and taxation to the vessel proper, the latter having to support and carry it.

I have endeavoured to devise a plan which would utilize and reduce this waste material, and I think this can best be done, in merchant and other unarmoured vessels, by combining the plating and frame in one; and, in armour-plated vessels, by combining the defensive armour partly or wholly in the construction of the vessel, which can be accomplished in the simplest and best way by using trough-shaped iron.

In merchant and other vessels I propose using iron of this description, from 15 to 24 inches wide, and in as long lengths as can be obtained—the width of the flange of the troughed iron being proportionate in scantling to the work it has to do.

In merchant and other unarmoured vessels the flanges should be inside, and the backs of the troughed iron outside. These several troughed frames are bent and bevelled to the various vertical sections throughout the whole or principal part of the vessel, the flanges of each successive frame being fitted closely back to back, and then riveted by hydraulic or other riveting machines. In this way, as a vessel is framed she is plated, and can be riveted, by mechanical means; and, excepting at the butts, and in the additional binding strakes of large heavy ships, no rivet pierces the web or shell. Where a bar keel is adopted, I propose using the garboard strake for connecting it with the ship. The attachment, however, will be much more complete on this principle, the

garboard strake having, throughout the entire length of the vessel, a continuous faying surface, instead of an intermediate one as in the present mode of construction.

In large heavy vessels, in addition to the garboard strakes, I propose fitting a bilge and sheer strake, which would also have a continuous faying surface and supported butts.

It will, I think, be admitted that the twisting strain in large vessels is that which it is most difficult to provide against and most detrimental to the structure; on this principle, however, owing to the bearing of frame to frame, there is a large supporting surface which gives this needed strength.

This principle has other advantages, for it reduces the weight of material and consequently increases the cargo capacity of the vessel—it is more economical in construction, and very considerably reduces manual labour—it gives a more perfect attachment of the beams to the whole structure, and brings into effective play the whole material in the keelsons, which are in direct connection through the flanges with the webs which form the shell, and it gives a more efficient attachment to the bulkheads, and distributes their strength throughout the structure.

I would dispense entirely with floors, and in lieu thereof adopt a larger number and greater strength of keelsons, which I attach directly to the flanges of the troughed frames, which connect them with the web forming the outer skins. (*See* Plate V.)

For steel of any scantling, and particularly for that which is very light, this principle is especially adapted, inasmuch as it is not necessary to pierce the web of the outside shell but in exceptional cases, and then only to a very small extent. This obviates the difficulty of a countersink in a very thin plate, and consequently a deterioration and wasting of the material around it.

In vessels of a considerable size, the thinnest steel that could be rolled in this shape might be employed in the webs, as these are supported at such close and continuous intervals by their flanges. The inside of the ship can be cemented flush, or nearly so, with the flanges fore and aft, so as to protect effectually the whole of the iron in the framework and shell of the vessel and make it easier to keep clean.

On this plan I claim that with less material, labour, and consequently less expense, a much stronger, more lasting, and more efficient ship, and greater dead-weight carrier, can be obtained.

With regard to iron-clads, I propose using the same troughed sections, but in this case working the flanges outside, not inside—the distance of the flanges centre and centre, and the thickness of the web being proportionate to the power of the guns to be resisted, these scantlings being considerably reduced below the water-line.

These troughed-iron frames I mould to the several vertical sections of the vessel or battery, and bring together flange to flange, as already described. These flanges I rivet together by hydraulics, and can obtain as great a pressure on each rivet as 50 or 60 tons, which will ensure the bringing home of each flange to its adjoining one.

The bottom, up to the water-line, I cover with wood by fitting three gluts in each of the troughs; the two outside being notched to bed the rivet heads, the third being driven in with a slight under-bevel with marine glue. This, when the glue solidifies, forms a compact glut in between each trough; these I plank again fore and aft, securing the planking by dump, wood, and screw bolts; this gives a complete independent wooden bottom, which can be caulked and made water-tight, and coppered if necessary; it also gives protection—as, if the vessel took the ground and tore any part of her

wooden bottom off, she would have an intact iron one below, the wooden one having acted as a fender and saved it from injury.

Above the water-line and over the battery I leave the troughed frames exposed for contact with shot or shell, considering that their effect on the shot or shell would be a shearing one, tending to break up such shot or shell before striking the web—this, again, being of sufficient thickness to prevent its becoming pierced by the pieces. In vessels where exceptionally thick armour is required, I propose, in addition, to fit extra troughed frames either longitudinally or vertically, in the wake of the vital parts of the ship, of such size and scantlings as may be necessary for the additional protection required; these being bedded on wood backing and secured to the structure of the vessel by bolts through the webs, and to each other by being riveted through their flanges.

This principle can also be applied to land batteries and other similar constructions, as these may be built on this principle entirely of iron and made self-contained and self-supporting. Floating oblong batteries could also be constructed on this principle for harbour defences, and subsequently if required could be utilized for sea-going purposes by having a bow and after-end built on to them. I am quite aware that trough-shaped iron has previously been used; but never, so far as I am aware, has it been applied, or suggested to be used, on the principle I now advocate, which is applicable in the construction of all classes of vessel.

A further advantage of combining the defensive armour in the construction of the vessel on this principle is that the fibre of the material is gained for resisting the impact of shot or shell; further, that no bolts are exposed, and that any damage necessarily is confined to a very small area.

This principle can be adapted in the construction of the batteries raised above the deck for offensive and defensive purposes; and further, for making a bomb-proof deck and bomb-proof bulkheads, as by making the flanges of sufficient depth the whole deck structure could be so formed as to obtain the necessary constructive and defensive strength.

DISCUSSION ON THE TWO PRECEDING PAPERS.

Mr. Edmund Thompson: Sir, I happen to be the youngest Member in this room. I only joined this Institution as an Associate a very few days ago, but I have had probably as large experience as most people in iron vessels. I have been nursed in them and educated in them; thirty years ago I was partner in the firm that built the first iron vessel that ever went across the Atlantic—the *Antelope*—and so well was she constructed, and of such good material, that she is now afloat under the name of the *Coral Queen*, and still doing good service. I have moreover been for the same period what is called a loading broker of vessels, and during that time I have taken a good deal of interest personally in superintending their stowage. From this I have derived a good deal of information which would be very valuable in technical schools, as it would save a great deal of trouble we now find with regard to the dismasting of vessels if the laws of gravitation, or in other words the laws of stowing weights, were better understood. With regard to the Paper which preceded this one I have some remarks to make. I disagree with the gentleman entirely that it would be desirable materially to decrease the depth and increase the beam of ships. My experience is the very opposite. About three or four years ago a

number of vessels came into use, the object of the owners being to get the largest weight-carrying compared with the smallest tonnage. Those vessels were from 240 to 260 feet long, about 42 feet beam, and only 22 feet deep. The result of those vessels has been most disastrous, and if Mr. Martell or any underwriter were asked he would say that no vessels have cost the underwriters so much money. I have known vessels of that construction to be dismasted twice on one voyage, and the reason is that the due proportion of breadth to depth has not been observed in the stowage of cargo, and you, Sir, who are well acquainted from your experience in the Navy in regard to the proper distribution of weights, know it is very desirable that we should lift the weights well up, and the vessel will not be a good vessel in a seaway unless that is attended to. In regard to the proper proportion of vessels, I think that a great mistake has been made in these modern times in going away from those very safe lines which were laid down by our forefathers. The old-fashioned plan of two-thirds of the depth to the breadth of the beam in my opinion was the right proportion, and I shall never rest satisfied, but shall continue to hold my protest against these broad shallow vessels that have such a tendency to be uncomfortable in a seaway. Another point is this, that in the construction of a vessel, or in the stowage of her—because we will go to that first, as I am speaking more of the subject of the distribution of weights—I have found from my experience, and it is the experience of all practical shipowners and shipmasters, that it is necessary to keep the weights out of the sides and ends of a vessel; and therefore in loading vessels you have to select either to go away with that space unoccupied or you must put very light cargo there. I will give you this instance, and it is a very familiar one. Some of you no doubt have been on the West Coast of South America and have there seen vessels laden with copper ore, and know I am right when I say that to bring those cargoes safely it is absolutely necessary that they should be built up like a cone. Another instance is vessels that have to carry cargoes of railway iron. There the same thing prevails, and I know from my own experience and from talking with captains of merchant vessels who have carried those cargoes that they would rather have them than many other cargoes. Now why is this? I think when we have arrived at that we may very possibly arrive at the reason why a total change in the present formation of iron ships should take place. The reason as I said before is that they keep the weights out of the ends and out of the bilges, and I maintain that there must be a totally new principle in iron shipbuilding, as it must be borne in mind that the old wooden walls did give a certain great breadth from where the cargo was carried to the water line which does not now prevail, and until that is done with iron vessels we shall have nothing but disasters occurring in our mercantile marine. The fact is that the centre of buoyancy has been disregarded. Look at the dimensions of a vessel that is very familiar to us all—the old *Great Britain*, a vessel of the fine old barrel-shape which you have probably seen. She is now thirty years old. Her dimensions are 350 feet long, 50 feet wide, and 30 feet deep, and although she was originally a very thin plated ship, such was her wonderful strong formation that she is now in as good a shape as ever she was. Now I will offer a few remarks as to Mr. Oswald's principle of building. I do not suppose there is a more intelligent shipbuilder than Mr. Oswald, or that there are many who have got a greater reputation than he has. I must confess I go a long way with him in the remark which he makes in the opening of his Paper when he says, "It is "notorious that there is a great amount of material not brought into useful and effective work in vessels." I have published a small pamphlet, which I hope will be in the acceptance of every one in this room, in which I make this remark—it is a very short one—"An avoidance of the present weak formation of the "framing of iron vessels which, as now placed, is in a vertical position and requires all the strength "of the plating to keep it together. Indeed, when any unusual strain occurs it is a source of great "weakness, as evidenced by the all-but certainty with which an iron sailing or steam vessel, getting on "a rock or on an uneven surface ashore, parts asunder." Now, Sir, I do not think that I need remark to you what a frightful thing it is to hear, day by day almost, of the foundering of merchant steamers and merchant ships—where in one moment, almost before they have time to breathe, the poor unfortunate crews are engulfed below the water. One remedy is suggested by the previous Paper of having the double bottom. I maintain that the only true remedy is to have the double side as well, and for this reason, following out the analogy of my argument, that by the shaping of the frame of the vessel in a position like the model I hold in my hand, I am enabled, having a double side, to keep my cargo freer from the water, and therefore can stow it in the proper position of buoyancy. I have placed in the room a large model of a ship showing my ideas. I am not at liberty to go into this, as I am not reading my own Paper and I only do it for the purpose of information, but I think at the present moment, when the

sad disasters which we have been lately having have stirred up the public mind very much on the subject, anyone who has thought deeply of it, and can bring some intelligence to bear by which those disasters can be averted in the future, is not doing bad service to his country. In its present formation I agree with Mr. Oswald that the frame of a vessel is in very great part useless to afford strength, but I am afraid he has weakened his vessel, nor has he got all the strength he should have, and if he had made his trough frames deeper, I fear he would only have increased his weights. Had he spaced the frames further apart, and connected them together by tie plates, as I propose doing, he might have arrived at a better result. I think we are indebted for wonderful improvements prospectively in shipbuilding to the extraordinary discoveries of Dr. Siemens and his steel; and there can be no question that the future prosperity of this country, if it is to hold its own as a mercantile country, will be largely indebted to that most valuable invention. I have gone into calculations and I find that a vessel can be built on a construction of a double formation such as I have indicated of this material, and which I am not going further to particularise, where the weight will be at least 10 per cent. less, if not 15 per cent. less, than the present mode of building, but where the carrying power on the registered tonnage, which you are aware is calculated on the inside instead of the outside of the vessel, will be no less than 30 per cent more. These are very startling propositions and I think are worthy of great consideration. I shall not detain this Meeting further than to state that I have prepared these models, and at any future time shall be glad to give all the information in my power. I consider Mr. Oswald has done great service in bringing this matter forward, and I hope the Discussion that will now take place on this very important subject will have this tendency, that it will call the attention of the public mind to the absolute insecurity of all single-sided iron vessels, be they employed in Her Majesty's Service or otherwise. The great mistake in my opinion in the construction of ironclads of the present day, or ironclads at all, is that the constructors have apparently forgotten the laws of gravitation; they have hung their armour plate on the outside of the vessel, causing her to be most uncomfortable in a seaway, instead of, as I propose, placing it alongside the inner shell of the vessel. This is a question of very large extent and I shall not go further into it. I am very much obliged to you for listening to me. I hope what I have said may receive, so far, acceptance, that people will be glad to hear more on the subject.

Mr. John R. Ravenhill (Member of Council): Mr. Oswald has brought a system of new construction of ship under our notice. I propose, in the absence of the writer of the first Paper, to confine the few remarks I am about to make entirely to Mr. Oswald's. There are two questions which struck me, and I believe they would strike any other practical man. I should like to ask Mr. Oswald, in the first instance, whether he has ever built a ship such as he has brought under our notice. That ship, if I understand him, has the seams and rivets all in one vertical line right round underneath the bottom of the ship. Now it is many years ago since a vessel was built in the Thames for the Admiralty—the *Grappler*—by the late Sir William Fairbairn, on that plan, in so far as this, that he connected his plates vertically from frame to frame. I am not quite sure whether at that period another ship or two might not have been built, but it is a system long since exploded. I should like also to ask him how he proposes, in the first instance, to get his joints, which are proposed to be made in this way [illustrating], so accurately square, and so perfectly brought together, as to give us that flat surface on the outside of his ship as represented on his model? My idea is that we should have some very funny places somewhere about the hull, unless it was all machined work and then brought together. The cost of that, I need scarcely say, would be enormous. I would also like to ask him what provision he proposes to introduce into the construction of his ship to make up for what appears to me, I will not say the want, but the deficiency at all events of tensional strength—such tensional strength, I mean, as is obtained under the ordinary system of construction in iron hulls? His model also shows us apparently one continuous plate right round the ship. I see no fore-and-aft flanges at all. Now plates like that would be impossible to obtain, and we should feel very much obliged to him if he would tell us how he would propose to work such plates into the very complicated forms that we know very often do occur in working both the bow and the buttock in iron ships?

Mr. Charles W. Merrifield, F.R.S. (Associate Member of Council): Mr. Chairman, I venture to suggest that it will be of very great advantage in clearing the Discussion if you allow these questions to be answered at once, for the whole Discussion really turns on them.

The Chairman (Sir R. Spencer Robinson, K.C.B., F.R.S., Vice-President): Perhaps Mr. Oswald will have the goodness to reply to Mr. Ravenhill, and it would be more convenient if he could reply to each question as it has been raised.

Mr. T. R. Oswald: The construction of the *Grappler* was very different, inasmuch as her frames were formed of T iron, and the plates which formed the butt strap to support the plates. That is a very material difference in the construction of the *Grappler* in that respect to what I advocate. I advocate the trough iron being rolled solid and having solid flanges—a converse moulded frame throughout the entire vertical section of the vessel, and brought into contact with the joining flange. These are brought together and riveted. As regards the practical difficulty of bringing those two flanges together I think there can be no difficulty in rolling that iron sufficiently sharp in the angle. If care is taken in the manipulation and the bending of the frames on the blocks before the frames come together, a very good and efficient joint can be made. I have not as yet built any vessel on this construction, but I have ascertained that iron, up to the width of 2 feet, can be rolled up to 30-feet lengths of that section; and as regards the butts in the vertical section, they are simply brought together and jointed by a butt strap of rather smaller section than the trough iron, bringing the two butts together. As regards loss in longitudinal strength, I think Mr. Ravenhill has lost sight of one very material thing, which is this, that in vessels of that construction below the centre—the neutral axis—there is compression, not tension, and the formation of these frames having the bearing flange to flange will very materially increase this longitudinal strength of the vessel. Further, in vessels of any size I propose working a continuous sheerstrake on the top, which, as the model there shows, has a continuous surface throughout the whole structure—not unsupported butts as in the present sheerstrakes, by which vessels are liable to twist in the rolling strain, and the butts are liable to work; but here the butts are supported throughout the whole length of the sheerstrake by the trough-iron frames, and the trough iron forms the inner butt strap, and they also have an outer butt strap. The garboard strake gives the attachment to the keel, and in very light ships we should probably work in a third strake on the bilges. There is very great difficulty in going into the calculations of a vessel of that construction so as to get the proper amount of strength of compression, but I feel satisfied in my own mind that a vessel built on that construction would compare most favourably with any ship constructed on the present plans, and as a whole structure would be almost as strong. As regards the difficulty of working vessels at the ends, I quite concur with Mr. Ravenhill's remark that there would be a difficulty, and at first sight I should propose stopping the trough irons within 10 or 20 feet of the ends, cutting off the large end, and forming that full with angle-iron frames, because at the end of a ship there is less strain comes on that part of the structure, and the strength of the structure is not so material there as through the main body of the vessel. I think those are all the points that Mr. Ravenhill referred to.

Mr. C. W. Merrifield, F.R.S: I was anxious to get those questions answered as a guide to the Discussion, because I was afraid that I might otherwise be addressing myself to shadows; however, as this seems to be really brought before us, it is necessary to point out to the Meeting, and call Mr. Oswald's attention to the fact, which I hope he will notice in his reply, that there are two sides to the neutral axis, and that on one side of the neutral axis the material is in compression at any given moment, and on the other side in tension. Now for compressive strain I certainly do see there is a certain provision made, but for the tensile strain on the other side of the neutral axis, on whatever side it may happen to be at a given moment, there is absolutely no provision whatever. This is evident to any one. I am very unwilling to go into practical questions, but this is a question of mixed theory and practice, and it is quite sufficient for the present to go into practical views. I think it will be obvious to any gentleman present, that when these plates come into longitudinal tension every joint may open to the extent of half an inch or an inch according to the size of the flanges, because I need hardly tell you there is no such thing as rigid material, especially when it comes to be exposed to such a foul strain as this. There is nothing to prevent the upper flange lengthening to the extent of several feet in a long vessel; and supposing that to take place on the top side, when the conditions are reversed, and the vessel is in the trough of the sea, there is nothing to prevent the bottom elongating to the extent of 3 or 4 feet likewise. That, of course, leaves the whole longitudinal strength of the vessel for all practical purposes absolutely dependent on the stringers, the garboard, and any other strake you may choose to put upon it, at a considerable distance from the neutral axis, wherever that may be. That seems to me to be sufficiently condemnatory of the system. I was particularly anxious to get a conclusive answer from Mr. Oswald to Mr. Ravenhill's questions, and I will try to direct myself to that, because this seemed to me at the first sight rather an extraordinary proposal to bring before a Meeting of this Society. With regard to the economy of the thing, in the first place the bending of trough iron is not a very economical process: the flanges of the

trough iron have to be brought together, because in the very act of bending them you shorten the inner edge of the troughs, and as you cannot practically shorten these, the effect is that it bulges them, and thus makes the flange out of plane, and getting that flange into plane is a serious and costly process of forging. Anyone who has any knowledge of the subject knows perfectly well the trouble you have with angle iron as compared with merely bending bars or plates, and the trouble of bending angle iron is very much less than that of bending a trough plate. So much for the economy in the midship body. Then when we come to the skew part, the ends, and so on, this process really seems to give what we as mathematicians call a developable surface—that is, a surface that can be made by bending a sheet of cardboard. You can build a vessel that will do a certain amount of work out of a sheet of cardboard (I have made myself many a toy in that way), but with iron you are very much restricted in shape; and, moreover, in cardboard you have the advantage that it bends almost equally well in all directions. That is not the case here. It evidently will bend very differently in different directions, and unless you go to the expense and trouble of rolling taper trough iron, analogous to what is done in Birmingham in making taper iron bedposts—and I never heard of its being attempted—unless you apply some process of the kind to trough iron I really do not see how you are to provide for the bow and the buttocks. Then there remains the question whether you cannot use the ordinary construction of iron ships for the bow and the buttock; but taking it altogether I do not see how any economy is arrived at, and the process seems to me to be ruinous and fatal with respect to longitudinal strains. I should not like to go to sea, or trust a cargo at sea, in a vessel of that kind. I should like now to make a few observations in reply to Mr. Thompson as to length and breadth. I was obliged to go away while Mr. Woolley was reading the Paper on the subject of length and breadth, but I should not like it to go forth that there are any definite rules such as Mr. Thompson supposes. All these questions about statical and dynamical stability depend on a proper balance being obtained, and provided a vessel be stowed in a proper way, there is no difficulty in getting a vessel, supposing the proportions are moderate, that will be tolerably easy in a sea-way, even supposing the proportion to be two to one of breadth to draught. Of course there are certain disadvantages attending those; so there are disadvantages attending all shapes. We know perfectly well that the old deep vessels, when they came to be stowed either with railway iron or copper ore in the bottom of them, rolled their masts out, and just in the same way, whenever you give too much stiffness the same thing will happen; but that stiffness can be avoided as well in a shallow and wide ship as in a deep ship, if she is properly stowed with suitable material and sent on a suitable trade. Therefore I do not think there is very much to be attained by starting with the notion that there are certain rigid proportions to be observed in ships, which if departed from will lead to mischief.

Mr. John Scott Russell, F.R.S. (Vice-President): I should not like to pass these Papers over without our getting the full advantage of the Discussion. There is no doubt of the great advantage of a due proportion of depth to breadth in a merchant ship. It has always been the thing most difficult to attain, and therefore I place great value on the last remark of Mr. Merrifield, that in almost every case the work to be done by the ship, and the conditions in which the ship is to be used, must dictate her proportions. As a general rule, I would say that shipbuilders of experience make the depth and the breadth of a ship of a considerable size, say 40 feet—such as he talks of—in the proportion of nearly, not quite, 3 to 4: thus it would be reckoned a very good proportion for a ship of 40 feet beam to be 30 feet deep. I think you may take that as a sort of average of the practice of professional men in ships of that size. Now I come to circumstances: The port out of which she is to sail happens to be a nasty shallow port; the 40-feet beam is very convenient for our purpose; we almost want a displacement which wants the 40-feet beam. Well, under those circumstances, are you to be forbidden building a ship of 40-feet beam, and, if you like what our friend says, 22 feet deep. Now I do not say that you are to be forbidden doing that. On the contrary, when I have been asked to build such ships to suit a given port, I have built them and found them answer their purpose, but only when in the hands of men who knew how to use them; for if they had availed themselves of this great breadth to shove great heavy weights out into the bilges, they would have paid the proper penalty; but when they were wise enough to mass all the weight in the centre, and only put the light stuff out to the sides, then they made a tolerable ship of it. In short I am afraid it comes very much to this—if you build a ship for me, build any shape you like provided you get a good captain and stevedore, and if the man knows where to stow his stuff, he can very often alter all the ordinary properties of a ship. Therefore I do not think there is anything to prevent a wise man from building a ship as wide as he wants her, provided he knows where the

other precautions are to be taken. That, then, gives no great latitude, but, like all latitudes, it requires considerable prudence in the use of it. The other point on which I would say a word is Mr. Oswald's plan of the structure of a ship. I fancy, Sir, you will not be astonished to hear me venture to say that the absence of longitudinal strength, or the diminution of longitudinal conformity in these days, when we make ships so long, and want so great longitudinal strength, rather, in my opinion, tells against that combination of material. I think it was one of the dreams of my youth, and you must laugh at me if you like for having been such a goose, that one day I should make a ship out of cast iron. I thought it would be such a cheap ship, because in those days wrought-iron plates were awfully dear. So I planned building out a ship of cast iron, and the way I took to make it of cast iron was to make it entirely of pretty tough plates, all cast each to the shape of the lines in which each trough-plate was to go, and then they were all to be planed nicely all round, and then they were to be beautifully bolted together; and in my dreams I fancied there would be the prettiest, the most beautiful, and most continuous ship made out of that that you could conceive. Now Mr. Oswald has quite approached to my idea of that shape, only the difficulties are, that he has not taken my beautiful plan of making a bow and a stern. If he would make a bow and a stern out of my cast-iron troughs, then he might make the bow and the stern as beautiful as he liked. That is the only suggestion I have to make of an improvement and addition to Mr. Oswald's plan, which will make it quite perfect according to my primitive idea.

Mr. Benjamin Martell (Member of Council): I should like to make a remark or two with respect to the subject which has been brought forward by Mr. Short in his Paper as to the difference in the proportions of ships. I certainly agree with Mr. Short that different proportions could be made to the steamers that we build at the present time, with great advantage. I believe the principle of extending the length of these ships in proportion to their breadth is wrong in many respects; that we could, with great advantage, increase the breadth of these ships in relation to their length; that we could make them more sea-kindly as ships—such as you, Sir, would perfectly appreciate, and I think such as everyone would prefer—whilst we could realise all the commercial advantages that we get from the ships of the proportions that we build at the present time. I remember, some time ago, a friend of mine in London consulting me. He was going to build two steamers, and because I recommended him to increase them 6 inches in breadth, he said, "I should be very glad to do so, but the fact is it will decrease the "speed half a knot." There is no doubt we have learnt sufficient of late to know that is an exploded idea—that you can in fact build a vessel of very much greater breadth proportionately and still get the same speed. But the difficulty I find is this—when you recommend additional breadth for a ship, the shipowner immediately wishes to carry out the ends of the ship proportionally in order to carry more cargo, precisely the same as he did in the ship with less breadth. I had a striking instance of that a week ago. A friend of mine, in London, was building a large steamer, and at my suggestion he increased her breadth a foot, and when the amended model came up it was found she carried immensely more cargo. I inquired into it, and found that the ends were precisely the same as the other ship; but if you increase the breadth and the fulness of the lines precisely as you would a ship of smaller breadth, and consequently carry a great deal more cargo, the inference is, and of course the result will be, that the ship will not be able to realise the same speed as the ship carrying the smaller cargo; but if you increase the breadth, and fine the lines so as to produce a ship of the same registered tonnage, she will be enabled to carry the same weight on the same draught of water; and I believe you will produce a very much better ship, and one that would, in my opinion, be altogether more satisfactory. The only question that arises is as to the stability. In this vessel, built and referred to by Mr. Short, there is no doubt that, when loaded with a homogeneous cargo like coal, it would not have too much stability; and it is possible to conceive that vessel equally well loaded with very heavy weights, if proper care is taken by the stevedore, but you cannot always depend on that. You could build a ship of any form, if you could only get her properly loaded, but you cannot depend on her always being so loaded, and you have to take the general circumstances of the case. The only fear that I have in these steamers, being so much less masted, and therefore having so much less weight above than sailing ships, is, that with some kinds of cargo, you might get too much stability, and in consequence they would be very uneasy under some circumstances. Therefore I should not like to go to the extent to which Mr. Short goes of increasing the breadth as much as 6 feet, and decreasing the depth to the extent he does, but still I think we may go with him to a certain extent, and alter the proportions of our steamers very materially in the direction he indicates, and produce very much better vessels. I have been reminded that in other yards this difference of principle has been carried out.

The CHAIRMAN: The principle referred to by Mr. Short?

Mr. MARTELL: Yes. Others besides Mr. Short have moved in this direction of giving greater beam. For instance I may mention Mr. Bone, of the School of Naval Architecture, and who formerly belonged to the Society I have the honour to represent. He is now principal managing director of a firm on the Tyne. He has carried out this principle, and the result is perfectly satisfactory.

Mr. T. R. OSWALD: Sir, I only have a few remarks to make on Mr. Russell's point, and the first I will make is with regard to the longitudinal strength which he seems to think is the very weak point in the construction I advocate. I think he has lost sight of the very material fact that in vessels of the present construction the whole of the frames, reverse, bars, floors, kelsons, beams, and stringers, are simply a disjointed mass until they are connected with the shell plating, and that mass again is connected by a rivet every 5 or 8 inches vertically and 20 to 24 inches longitudinally, and when it is borne in mind that in that mass of material fully $\frac{3}{5}$ths of the total weight of iron is used up, I think it must be forced on the mind of all present that the present construction, whatever mine may be, is a very weak one. What I endeavour to aim at there is yet to get a continuous supported mode of construction. Below the natural axis there is no question that I gain compensation to assist the longitudinal strength, and in large vessels I should never think of simply leaving the riveted joints to do the whole longitudinal work, and to meet that, as my model shows, I propose working a sheerstrake fore-and-aft. I claim that for this construction I obtain much more work out of the iron in the sheerstrake, than in the present mode, simply because it has a continuous framed surface throughout fore-and-aft, and supported butts; and everyone knows that in ships we may say theoretically the longitudinal strength is so and so, but in point of practice it is not so. The vessel gets on her beam ends in a heavy sea way, and there is a twisting and a tortile strain going on which racks the butts, and being only supported on one side to a great extent affects the whole structure. I think this plan obviates all that difficulty to a very great extent. As regards cast iron, certainly I never have had such a dream as that of Mr. Scott Russell. It may in some cases be a very easy mode of construction, but I am afraid with that it would be rather an unsatisfactory one.

The CHAIRMAN: Gentlemen, I am sorry that Mr. Short was not here to read his own Paper, and to join in the very interesting Discussion we have had upon the subject of length to breadth. I think that the teaching of this Institution has been so far of use to myself that I have come to conclusions with respect to the breadth of ships and their length which were not in my mind before I had the advantage of hearing so much as I have heard on the subject within these walls, but of course I am not in the Chair to give you my opinions upon any of these matters. I only think that we may pass a vote of thanks to Mr. Short for the Paper that has been read to us, and for the interesting Discussion that he has been the means of bringing about. I entirely agree with what has fallen from Mr. Scott Russell and others that this matter of length and breadth is above all things a subject for discussion, and that you want, in all the tools you do make, to know first of all what use you intend applying your tool to, and then you can construct a tool that will supply your demand and fulfil your wishes exactly. The stowage of a ship is one of the features of making a ship easy, and the stowage of a ship, if the forms are not extremely varied and unlike those in general use, will determine most of her qualities. With regard to the second Paper, it is practically one fit for the judgment and discussion of shipbuilders and practical men. I wish to offer no opinion on the subject. It is an interesting matter, and it would be of course a very great gain to the service of the construction of ships if the whole of the material employed in the ship could be made to bear, every portion of it, its due strain. Perhaps there is not in all longitudinal constructions as much strength as there ought to be, but I must leave that question entirely to the appreciation of those Members who are practically connected with the subject. I think we may also thank Mr. Oswald for having brought a very interesting subject before us.

ON THE CONSTRUCTION AND BUILDING OF YACHTS.

By John Harvey, Esq., Shipbuilder, Wivenhoe, Member.

[Read at the Nineteenth Session of the Institution of Naval Architects, 12th April, 1878; Admiral Sir R. Spencer Robinson, K.C.B., F.R.S., Vice-President, in the Chair.]

Yacht construction, the construction too of ships of war and naval architecture generally, form one of the most engaging, and to those who wish to make them a success, one of our most economically pleasant callings. The vast sums of money that are invested in bad conceptions of what is required for a good sea-going and fast yacht (and this may no doubt also be said of war ships) are enormous; but the end of blunders it is to be hoped is near, since we have in our Royal Schools of Engineering and Shipbuilding, and this admirable Institution—an extended resuscitation of the famous College of Naval Construction—an Institution which turned out the men who now have millions of this country's money to dispose of in the shape of ships for our Navy, to which branch of our Service we at all times, and in no time so much as at present, trust so much.

I have purposely left out the mention of our merchant navy, not from any disrespect of the abilities of the naval architects of cargo-carrying vessels; for, in these vessels—which sometimes have to make voyages at one draught of water, and sometimes at another—the scope for study to make them good sailers, and good sea-going vessels, is comparatively unlimited.

Assuming, therefore, our ground to be that we are about to construct a vessel on a given load water-line, and therefore that the weights she has to carry are fixed upon, and their position known, we must at the start know what portion of the weights will be required for the formation of her hull and equipment. To this end I some years ago began to submit to the public, through a friend, articles on yachting,* and in the orthodox fashion hunted up the name of the builder of the first yacht, &c., but from pressure of business my first article was unfortunately my last, and Alpha and Omega were one, so to speak; and these articles were an introduction, until some eighteen months ago the subject was revived under the heading of "Yachting Lloyd's."†

This, like my article on yachting, was not long-lived of itself, but from the lively interest taken in the matter by some of our leading yacht owners, and from the care the Committee of Lloyd's British Registry of Shipping has taken to realize that the Rules Yachting Lloyd's proposed for the shift of and schemes of scantling for the building of yachts are what is required, there will in a short time be before the public Rules by which, if adopted, yachts will be eligible to be classed as the number of years and the material used in their construction, &c., allows, just as vessels in the merchant service are now classed.

* See *Once a Week*, April 11th, 1868. † See *Field*, December 9th and 30th, 1876, and January 6th, 1877.

Assuming that such Rules as Lloyd's (to be called Lloyd's Register, &c., for Yachts) become the basis on which naval architects may found their plans, so far as providing sufficient displacement for carrying the weight of the structure, with the other weights to be carried, and assuming that the designer has, although not that advanced stage of culture so vividly illustrated by Mr. W. H. White in his Paper, read at our Autumnal Session at Glasgow in August last, yet a fair knowledge of naval architecture (I would beg here to presume that Mr. White concluded the Paper in question at the very point at which the young aspirant in naval architecture would be most interested in—that is, to apply his education to a design), a starting point is arrived at for a design.

As a designer of vessels for most purposes except for the purposes of war, and as I have been free to construct as I pleased a great number, it no doubt appeared stranger to me after thirty years' practical work than to Mr. White that he could no longer help the pupil, and it is at this juncture of the naval architect's course of study that I think some help may be given him.

As the subject to be treated on is the construction of yachts, and in order to distinguish one from another, I presume the best sea-going and fastest yacht of her tonnage to be required. Naval architects and yacht builders must here understand that I am not speaking in an egotistical sense, but merely assuming for a purpose a definite ground. The same view, of course, will be taken of my apparent presumption to add to what Mr. White gave us as the course of education of a naval architect, and also viewing the subject, as we must, as one of an inexhaustible nature, the remarks which follow can be deemed only as hints towards an end, adding at the same time that the whole string of aequirements, such as the finding of the different centres, &c., &e., which Mr. White gives as the course of study,* are mainly called into play in designing a good and fast-sailing yacht; and to this string of acquirements may be added that of immersed and emersed wedges at the different angles of inclination, so that as the yacht careens over, her centre of buoyancy is not altered longitudinally. Careening appears to me to have been lost sight of in these days of steam. But for sea-going sailing yachts, the importance of watching narrowly anything in the vessel's shape which would tend to alter the centre of buoyancy longitudinally, or to any great degree vertically, we consider of the utmost importance.

Volumes may be written, as this Institution is well aware, from the long discussions which have taken place within these walls, on the subject of the best proportions to be adopted. This question I would beg to treat in a very summary manner, by taking the dimensions of certain yachts which have been built, and their properties tested; and that I may not go over a long course of years (except to mention that some twenty years ago our then recent experience induced us to construct a boat for ourselves of the type and nearly of the proportions of the longest vessel I am about to notice †), I will here bring to your notice four vessels of nearly equal tonnage, one of the greatest beam, two of medium beam, and one of the least beam in proportion to its length that we designed, *viz.*:—

			Ft.	Ins.			Ft.	Ins.
Rose of Devon,	length on L.W.L.	...	81	9	main breadth	...	20	5
Sea Belle	,, ,,	...	90	9	,,	...	18	11
Miranda	,, ,,	...	86	4	,,	...	18	$11\frac{1}{2}$
Jullanàr	,, ,,	...	98	6	,,	...	16	11

* See *Transactions* of the Institution, Vol. XVIII., p. 366. † The *Kitten*.

I mention the *Rose of Devon* in connection with the three last-mentioned vessels on account of her being a fair illustration of light displacement, and because she is yawl-rigged as *Jullanàr* is, while the *Sea Belle* and *Miranda* are schooner-rigged, and of medium displacement as compared to *Jullanàr*. *Jullanàr* is the opposite to *Rose of Devon*, and is, as compared to her, of very heavy displacement. The subject of displacement I will notice later on.

Drawing No. 1 shows the sheer plan, with the longitudinal curves, of these four yachts.

Green is *Rose of Devon;*
Black is *Sea Belle;*
Red is *Miranda;*
Blue is *Jullanàr.*

By the curves I mean the centres of gravity or bulk of the immersed portions of the fore and after bodies at the respective water-lines shown.

The outlines of each of the vessels illustrated start from the centre of buoyancy in a fore-and-aft or longitudinal direction (*see* line on Drawing No. 1, marked A).

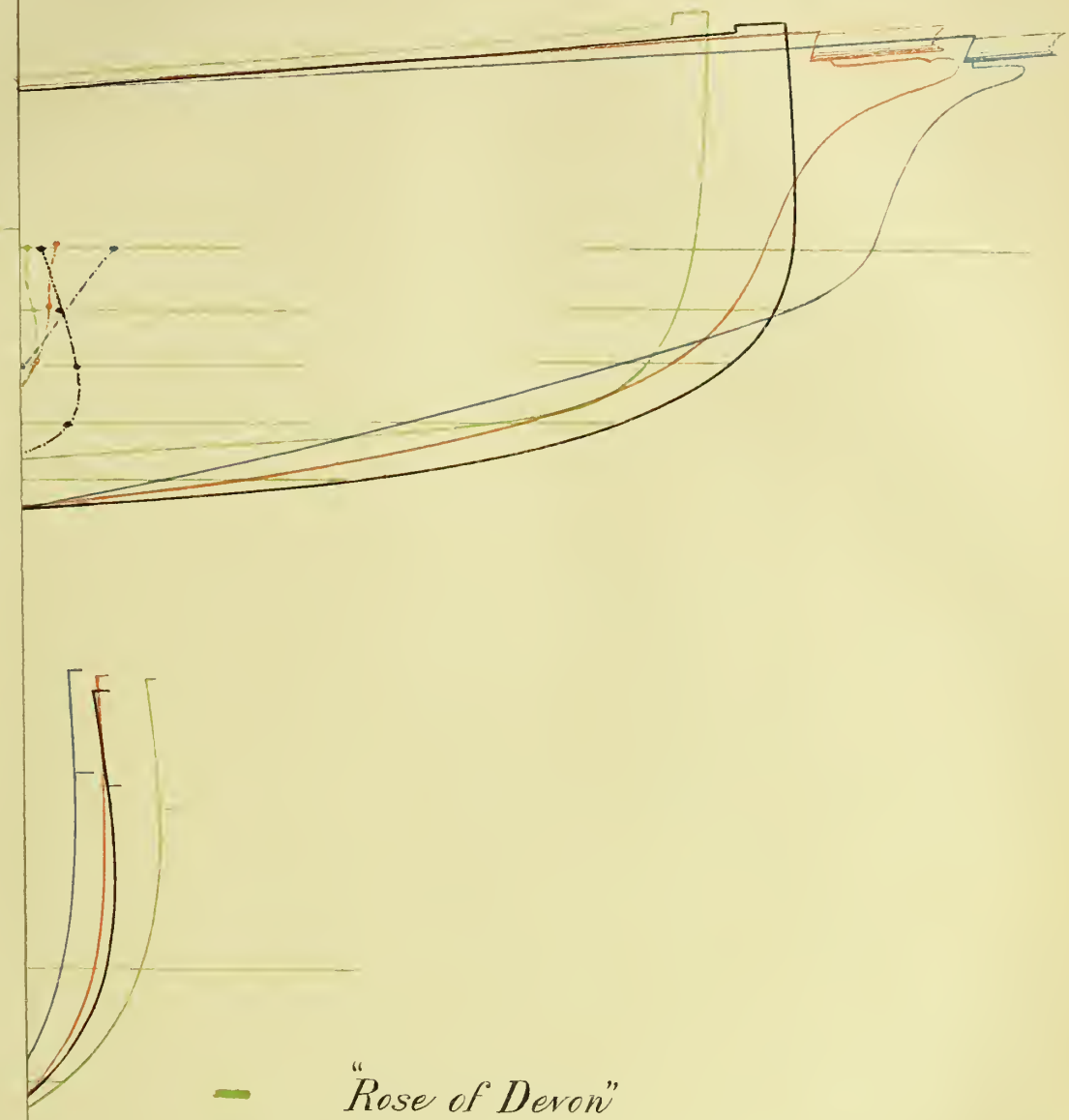
Drawing No. 2 shows the half of the midship sections of these four vessels in like colours, and the usual symbol for indicating the centre of buoyancy indicates the centre of gravity or bulk of the immersed portion of their half midship-sections. The two sections shown on the opposite side I will notice later on.

I am quite aware that, in showing such contrasts as are before you, it may be said that the student who wished to put into shape his knowledge of naval architecture must have some definite dimensions given him. This I beg to point out raises the question of whether a beamy or light-displacement vessel is determined on, or whether a narrow and heavy displacement is chosen; and I would here remind you that I started with the motto of producing the best sea-going and fastest yacht, and if this is determined on, I am of opinion that dimensions similar to *Miranda's* are for all purposes the best, at all events for racing purposes (and in saying "racing purposes" I include, as well, good, but not the best, sea-going qualities). I would not go as far as *Jullanàr's* proportions for, mark as she has made by her actions, there are times when vessels of *Miranda's* dimensions would prove to be the best general racing boats. Allowing, therefore, that *Miranda's* dimensions may be adopted, and noting what a slight difference there is between her dimensions and *Sea Belle's*, the student, with the position and shape of their midship-sections given him, must now make his drawing, and when made, go through the necessary calculations to find what I have termed the centres of bulk or gravity. The same deduction applies if it is determined on to adopt light displacement, as illustrated by *Rose of Devon*, or heavy displacement, as illustrated by *Jullanàr.*

On Drawing No. 1 is also shown the centre of gravity of each water-line, indicated in like colours.

Of the peculiar shape this assumes on the sheer drawing little need be added, for I refer to it here only for the purpose of fixing on a starting point from which to give the measurements of the centres of gravity or bulk of the fore and after bodies, and I touch upon it hereafter in connection with what particular requirements it is desired to attain.

On the distances these centres of gravity of the fore and after bodies are from the main centre of gravity of each water-line—taking into consideration at the same time the displacement of the midship-section—depends the sea-going qualities of the vessel



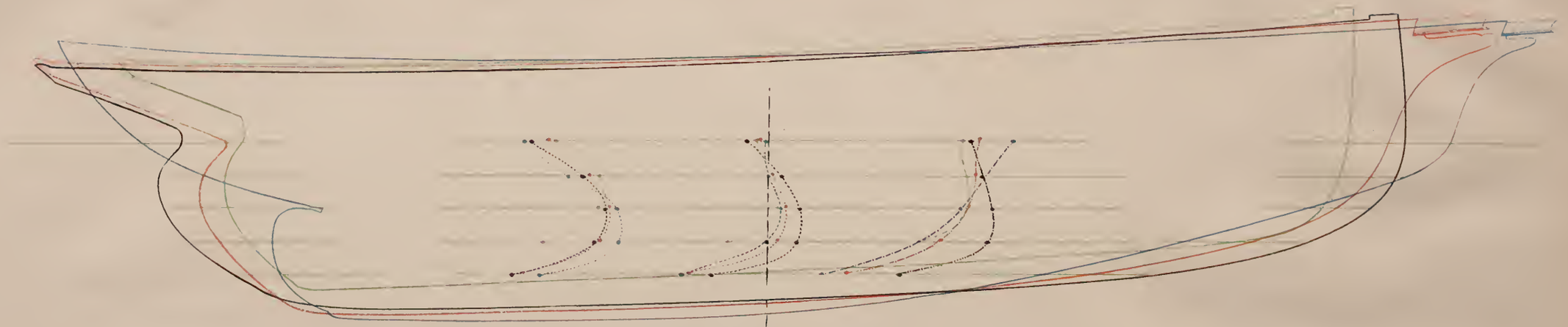
"Rose of Devon"

"Sea Belle"

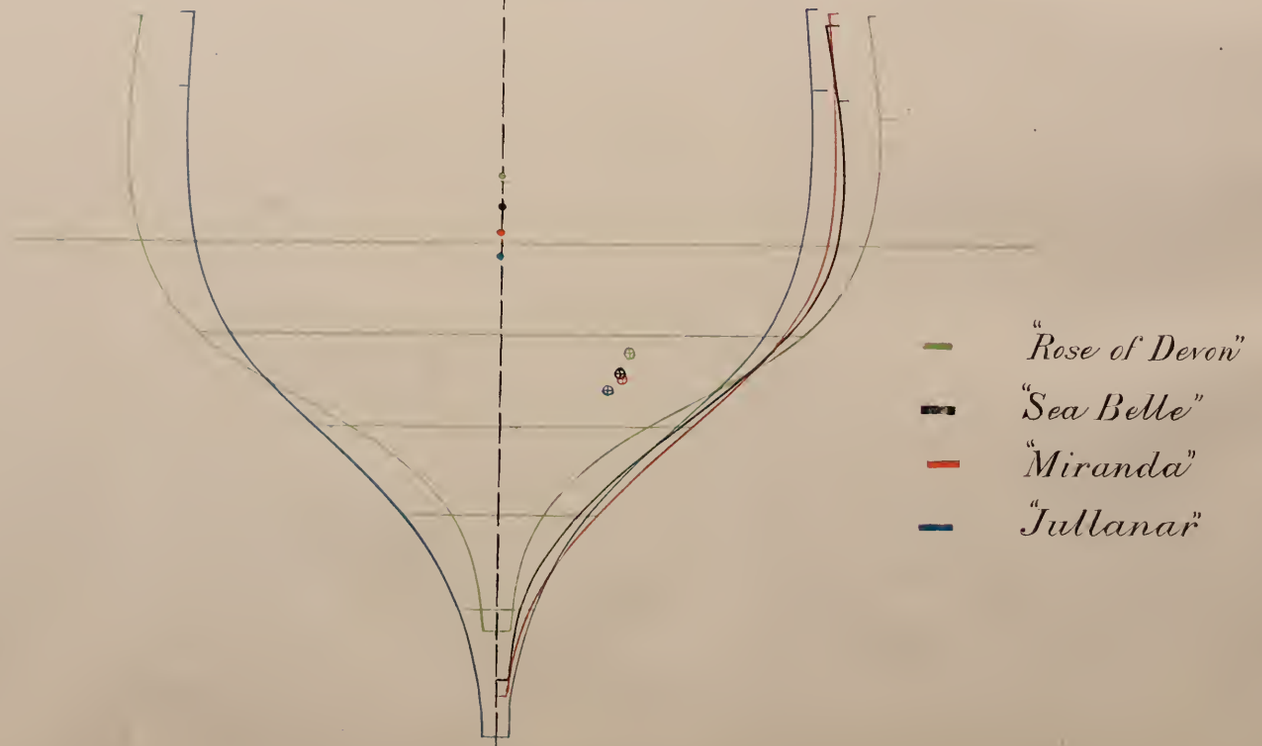
"Miranda"

"Jullanar"

To illustrate Mr. John Harvey's Paper on the construction and Building of Yachts.



Scale: ⅛ Inch = 1 Foot.



Scale: ¼ Inch = 1 Foot.

designed; and this I consider, as compared with speed in smooth water, of much the greater importance; for to outdo a vessel of equal tonnage in a sea-way, while one's opponent can hold her own in smooth water, I deem a double honour, as in the former we have what yachts should be—easy carriages on the troubled waters to be at times contended with; while with many yachts that are fast when the water is smooth, they are not fit to be pressed in a sea-way. This may be witnessed any day, even on the Thames, when there is a strong wind; for, on entering Sea Reach, yachtsmen that may be here have witnessed boats of 50 tons come up to others of more than double their tonnage, when the motion of pitching and 'scending takes place. In this particular I am tempted to refer you to what I stated in this Hall, in April, 1876, respecting the *Jullanàr*,* and to add, that no nautical man or naval architect that saw her or her drawings would agree with me, except my co-worker, Mr. Pryer, that she, from want of what is termed fore-foot (or draught of water forward), would go to windward; and here I may also remind you of the decision arrived at by the judges at the Shipwrights' Exhibition [illegible] with

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[illegible] (a Table showing the position of the centres following on) were arrived at from what I, on Drawing No. 1, show as their curve of centres, and which illustrates crudely the special qualifications of each of these yachts. To make this plain, I beg to add, that if *Sea Belle* is put on a wind—that is, beating to windward—she has in her the essentials of at all times outdoing *Miranda;* and *Miranda* has in her the essentials of at all times outdoing *Sea Belle* reaching, or when the force of propulsion is abeam. To touch upon *Jullanàr* (as compared with the last mentioned two yachts) is comparatively forbidden ground, seeing that I have adopted *Miranda's* dimensions as being best; still, allow me to add, just as a word in passing, that in anything like a breeze, she, from her great length and draught of water, will outdo both of them, either on a wind or reaching; and had she been built as designed would have done more than she is now able to do. But to return again to the consideration of a yacht on *Miranda's* dimensions—for what these vessels can do is void of the question so far as naval architecture (in a sense) is concerned, as compared to what I have just lately stated as the essential points of difference between them—I must now again draw

Erratum.

Page 153, foot-note, for Volume XIII. *read* Volume XVII.

* *See* Volume XIII., page 326, of *Transactions* of Institution of Naval Architects.

designed; and this I consider, as compared with speed in smooth water, of much the greater importance; for to outdo a vessel of equal tonnage in a sea-way, while one's opponent can hold her own in smooth water, I deem a double honour, as in the former we have what yachts should be—easy carriages on the troubled waters to be at times contended with; while with many yachts that are fast when the water is smooth, they are not fit to be pressed in a sea-way. This may be witnessed any day, even on the Thames, when there is a strong wind; for, on entering Sea Reach, yachtsmen that may be here have witnessed boats of 50 tons come up to others of more than double their tonnage, when the motion of pitching and 'scending takes place. In this particular I am tempted to refer you to what I stated in this Hall, in April, 1876, respecting the *Jullanàr*,* and to add, that no nautical man or naval architect that saw her or her drawings would agree with me, except my co-worker, Mr. Pryer, that she, from want of what is termed fore-foot (or draught of water forward), would go to windward; and here I may also remind you of the decision arrived at by the judges at the Shipwrights' Exhibition, where her model was put in, in competition with other yachts.

But I am straying from my subject, and return to again endorse my previous remarks, *viz.*, that our basis for a good all-round boat shall be on similar dimensions to *Miranda*.

I must here claim your attention to the little difference that exists between the dimensions of *Sea Belle* and those of *Miranda*, and what caused the difference there is in the models of these two vessels. I would do so by first quoting what I wrote to the Secretary of the Shipwrights' Exhibition. Of *Sea Belle* I said, "Our principal aim in "this design was to make her a success as a weatherly vessel (and I may add, beat "*Pantomime*), keeping an eye on producing a good sea-going craft at the same time. "We claim for her a success, as she is famed for both the above qualities; and in "skilful hands, such as Harlow's or Downes', can beat any of her class, especially in "a head-wind."

Of *Miranda* I said, "She differs from *Sea Belle* only in respect of her reaching "qualities, and may be termed a more general racing craft."

These conclusions (a Table showing the position of the centres following on) were arrived at from what I, on Drawing No. 1, show as their curve of centres, and which illustrates crudely the special qualifications of each of these yachts. To make this plain, I beg to add, that if *Sea Belle* is put on a wind—that is, beating to windward—she has in her the essentials of at all times outdoing *Miranda;* and *Miranda* has in her the essentials of at all times outdoing *Sea Belle* reaching, or when the force of propulsion is abeam. To touch upon *Jullanàr* (as compared with the last mentioned two yachts) is comparatively forbidden ground, seeing that I have adopted *Miranda's* dimensions as being best; still, allow me to add, just as a word in passing, that in anything like a breeze, she, from her great length and draught of water, will outdo both of them, either on a wind or reaching; and had she been built as designed would have done more than she is now able to do. But to return again to the consideration of a yacht on *Miranda's* dimensions—for what these vessels can do is void of the question so far as naval architecture (in a sense) is concerned, as compared to what I have just lately stated as the essential points of difference between them—I must now again draw

* *See* Volume XIII., page 326, of *Transactions* of Institution of Naval Architects.

your attention to Drawing No. 1, and it will be noticed that the black line representing *Sea Belle's* curve of centre of gravity of fore body, as well as that representing the centres of gravity or bulk of the vessel at the respective water-lines, especially in the fore body, are much more curved forward than the red one representing the *Miranda's* like curve of centres. In this curving forward lies to my mind the secret of designing a vessel for the special purpose of beating to windward. This difference may be treated as of slight importance, but that I may be understood to rely very greatly on the comparatively small difference, I would, were I called upon to beat either of these vessels on their chief merits, carry out this theory to a greater extent; and that it may be understood that I do not claim anything further than drawing the attention of naval architects to the fact of this being the principal point of difference between *Sea Belle* and *Miranda*, still to this alone do we attribute greatly the difference of the performances of these two yachts. I may at the same time mention, that some twenty years ago, in designing the *Peri* for the fruit trade, I practised on this theory for a close-winded vessel to a far greater extent than is done in *Sea Belle;* and I may also add that the model of a Penzance or Mount's Bay fishing craft far outsteps her in this particular.

The position of these centres of gravity of the fore and after bodies, from the centre of gravity of each water-line, is—

		Rose of Devon.	*Sea Belle.*	*Miranda.*	*Jullanàr.*
On the load water-line	Fore body	·352	·348	·331	·364
	After body	·403	·389	·4	·379
2·5 below the load water-line	Fore body	·334	·332	·342	·349
	After body	·33	·35	·357	·362
5·0 below the load water-line	Fore body	·353	·338	·342	·357
	After body	·361	·341	·339	·368
7·5 below the load water-line	Fore body	·378	·374	·361	·378
	After body	·402	·368	·348	·338
10·0 below the load water-line	Fore body	000	·406	·43	·40
	After body	000	·44	·412	·39

Here I beg to remark that it would have much simplified the above Table had the position of the different centres been given from the line (A) shown on Drawing No. 1, which represents the position of the centre of buoyancy longitudinally of each vessel, but the outlines being ostensibly to illustrate how one vessel differed from another in fineness and peculiarity of form, I deemed it better that all the outlines of the vessels illustrated should start, as I have before remarked, from a line representing the longitudinal position of the centre of buoyancy of each vessel; and here I may further remark, that a comparison may be made with the distance our centres of fore and after bodies are from the centre of gravity of each water-line as illustrated by Mr. Scott Russell's wave-line theory,* and by taking note of what distance the centre of gravity

* See *Transactions* of Institution of Naval Architects, Vol. II., page 236.

of the water-lines crosses the centre of buoyancy of the respective yachts illustrated on Drawing No. 1, and referring to the Table, taking the average distance of the centre of gravity and the centre of gravity of the fore and after bodies, it will be found that (allowing that the architect has not an unlimited length of midship body) we differ considerably from the wave-line theory, for whereas the wave-line theory gives the centre of gravity of fore body at ·29 from the centre of gravity of each water-line, the Table shows that those centres of the vessels illustrated are ·34 at the load water-line. For fast cargo-carrying vessels I have found that the centre of gravity of the fore body should not be less than ·39 from the centre of gravity of each water-line, this being what the *Zizine*, a 300-tons merchant vessel, worked out, which we designed some eighteen years since.

I may mention, that I find it was for our Session of 1865, that I wrote a Paper, and among other things drew attention to the position of the centres of the fore and after bodies, but which Paper, from illness, I did not read. While on the subject of the centres, and particularly that of the position of the centre of buoyancy, I beg to draw your attention to the necessity of testing the design at different angles of inclination; for if these centres are allowed to move in a longitudinal direction, as the vessel heels over (and they do so move in faultily-modelled vessels), her pitching and 'scending motions are accelerated, and account for the picture I drew of a small vessel beating a large one in a breeze, or on entering rough water.

I will now draw your attention to Drawing No. 2, on which is shown, as I have before remarked, the midship sections of the four vessels referred to, with the centre of gravity of each half-section shown thereon, simply to remark that in *Rose of Devon* (the vessel of less length in proportion to her breadth that this Paper refers to) as compared to *Jullanàr* (the vessel of the greatest length in proportion to her breadth) is a fair representation of natural, while the latter is a fair illustration in vessels of this tonnage of artificial stability, and that natural *versus* artificial stability may be considered, the two vessels of like dimensions (*Sea Belle* and *Miranda*) shall, with the previous remarks of comparison between them, not be considered in the present case.

The subject therefore before us is, natural *versus* artificial stability; and allow me in the offset to say that, odd as it may appear, I, for the purpose of sea-going, prefer the yacht of artificial stability; for, be it noted, that on Drawing No. 2, I have, as well as showing where the centre of buoyancy of the half-section is, also shown the metacentric height of each of these yachts; thus comparing the centre of gravity of section of *Rose of Devon* with that of *Jullanàr* in relation with their respective metacentres, and, allowing that both vessels are ballasted as best suits their forms, it will be found that whereas *Rose of Devon's* metacentre is 1·9 above, *Jullanàr's* is ·41 below the load water-line. This gives the *Rose of Devon* an artificial air-box which at a certain list helps her greatly in resisting the force used to press her over, and does not call upon her centre of gravity of ballast like *Jullanàr* does; which vessel, by reason of her not having the air-box represented by the distance between metacentre and load water-line, trusts entirely to her low centre of gravity of weight or ballast and her natural air-box above the line of flotation in the shape of freeboard. By natural air-box, I would wish to indicate the area between the metacentric plane and that of the load water-line. It therefore follows that great things may be expected in light winds, or with an even pressure of propulsion and tolerably smooth water, from

beamy vessels, while long, deep vessels, seeing that their metaeentres are so low, and bearing in mind their depth and low centre of gravity of ballast, are prepared to take any list they may be exposed to, without endangering their commander's ability to keep them under proper control. I wish it at the same time to be understood that for eruising purposes the beamy vessel, properly rigged, is a good type of yacht.

This brings us to the question of sail-carrying power, or the power one vessel has eompared with the other to carry sail with safety; and to substantiate the ground taken, I must ask you to picture *Rose of Devon* and *Jullanàr* put in competition with each other, and that each yacht has all the canvas spread she can judiciously carry; and owing to the ehangeable nature of the force of the wind to be at almost any moment more or less. To make the pictured eircumstances of the trial complete, we must assume, knowing that we are always liable to it, that an extra force of wind eomes upon each of the yachts we have under consideration—What then becomes of natural as eompared with artificial (as it is termed) stability? The vessel of natural stability has, previous to the storm striking her, just as the vessel of artificial stability, all the sail spread that will propel her best, that is, she is pressed to the extent that her natural stability is telling best with her opponent, but the moment the extra wind strikes her sails, she must let run some of her means of propulsion, and not allow herself to be laid over to a great angle, as her natural stability is now brought to do more than is provided for, while the yacht trusting to what is termed artificial, but whieh (under the pietured circumstances) becomes real stability, defies the extra force of wind, and would seem, I venture to submit, to have no danger point, even although compelled to take a few more degrees list.

From the foregoing remarks we may assume that for the safest and fastest yachts across the sea, or in matehes where a reef or two have to be hauled down and sea has to be contended with, *Jullanàr's* dimensions are recommended; and I would here remark that should this idea be endorsed, and the naval architeet be called upon to design a *Jullanàr*, or one to surpass her, let her peculiar outline have his minute study (I do not mean above water when in a quiescent state higher than her line of immersion to say 18 degrees); for, narrow and deep as she is, he will find reason for sticking most indomitably to the outline of her plane below water, especially that of her centre of lateral resistanee, after he has studied the other eentres that are shown by Drawing No. 1.

Assuming still that the designer has now seen the reasons for my advising *Miranda's* or *Sea Belle's* dimensions being adhered to when he is called upon for a racer, either for a particular trait of eharacter or for general racings, or for sea-going, and the safest ship, a *Jullanàr;* let me impress upon him that he has to rig her, for it will not do for him to think on his having completed the lines of a yacht that he has done, and allow advisers to step in to show him where his mast or masts are to be placed, or where the centre of effort of his sails is to be, as the end of that would be, as we often witness, that large removes would have to be made.

It therefore follows that when due respect has been paid to the centre of gravity of the fore and after bodies of the design, and the eentre of lateral resistance is found to be in proper relation with the centre of buoyancy, he must now insist on so rigging his yacht that the centre of effort of his sails agrees with his centre of lateral resistance, not forgetting that his ship has to go through rough as well as fine weather, so that in the reduetion of canvas from what is required for fine weather to that suitable to a

storm, he still maintains the same balance by keeping the centre of effort in the same longitudinal position.

Here I might remark on the extraordinary alterations I have known designers of yachts to submit to, so far as their rig is concerned; but, as I said at starting, I do hope now that these blunders are at an end, and that the iron will of the naval architect will predominate, and be looked upon by his nautical assistants with respect, so as to convince those who have not studied naval architecture, but have at the same time turned out good vessels, that the time has now come to do with their models as I have done with the four to which the previous remarks refer, and let naval architects know what good or particular points he or they think they have in them.

In a previous part of this Paper I said I would refer again to the subject of displacement. Allow me to say that in comparing *Jullanàr* with *Rose of Devon* I therein portray the great odds that exist in yachts of what are termed of nearly equal tonnage. A wide difference exists in them essentially by reason of their displacement varying so much; and in a few words allow me further to add that it is this question of tonnage and dimensions *versus* displacement that so much upsets the yacht-owner and yacht-builder as regards the price per ton to be paid for a yacht; for allow me to point out to you that *Rose of Devon*, of 148 tons, has a displacement of but 128 tons, while *Jullanàr*, of 124 tons of one measurement, and 136 of another measurement (and the latter takes in the whole length of her water-line), has 156·6 tons displacement. The *Jullanàr* takes 81 tons of ballast, and requires this to be of lead; the *Rose of Devon* takes but 57 tons, which, to prove her qualities, may almost as well be of iron as to be of lead—then comparing the different centres of gravity of these two structures as hulls ready to be masted, the one taking lead and the other being ballasted with iron, consider for a moment what is required to get the best out of each of them. As naval architects I feel sure you will agree with me, that he who wishes to turn out the best racer, the best sea-going vessel, and the best vessel for accommodation and comfort while at sea, will recognize as constructors and builders the almost insurmountable difficulty, in a commercial sense, of turning out the best yacht; at the same time he has the consolation of having put before the world structures in which when in heavy weather no danger point exists, bearing out what I said at the beginning of this Paper, that the science of naval architecture is a most economically pleasant calling. And now, mixing trade with profession, allow me to add that if it be asked what purposes are served by taking all the trouble one does in designing yachts, allow me to explain, that good principles carried out, whether in yachts, merchant vessels, or vessels for war purposes, I think repay the constructor; for if it is a fact that vessels of *Jullanàr's* proportions are the best sea boats, why should we not have a few of them (with auxiliary steam power to be used only in calms) for the training of our lads for the Navy and for despatch vessels, saving as they would an enormous expenditure on what is required for propelling our present ones while under steam, and avoiding it may be such catastrophes as we all, but too recently, deplore.

The building of yachts, as the best sea-going vessels, I intended this Paper to include, but, as I remarked in its early stages, this I leave to Lloyd's Registry of Yachting Committee, feeling confident they will adopt such schemes of scantling and modes of build as are equal to the strain put upon them as yachts, let them be of wood, iron, or steel, or a mixture of the three. I would at the same time add, that what I consider preferable to either iron or steel, or a mixture of iron or steel with wood, is

a wooden structure (that is, wood and copper) put together as nearly as possible in the same fashion as either iron or steel is, so far as wood can be applied.

The model on the Table shows this build so far as the floor timber and keelson form the structure. This mode of construction was first carried into practice by us in vessels of *Sea Belle's* tonnage in 1873, after submitting it to Mr. Welch, the late Superintendent of Her Majesty's Cruisers, since which time nearly all the yachts we have built have been constructed in the same manner.

It will be seen that contrary to the mode adopted in Her Majesty's Service with double outside wood-skinned structures, in which angle iron is used for frames, we have adopted moulded wood timbers at spaces sufficient to get the model of the vessel, and filled in the remaining spaces with bent-wood timbers at intervals which we deemed sufficient to give the necessary strength; our experience being that with a single outside planking of wood, from the difficulty of isolating the iron frames from the copper fastenings in the planking with cement, through the fact that the caulking and the swelling of the woods disturbed any cement put in for that purpose—no such sufficient strength and durability can be well attained; and that for yachts, when two thicknesses of outside planking are adopted, iron frames are an expense not needed.

ON THE CONSTRUCTION OF COMPOSITE YACHTS, ILLUSTRATED BY THE MODE ADOPTED IN THE "SUNBEAM" AND A NEW YACHT.

By St. Clare J. Byrne, Esq., Member.

[Read at the Nineteenth Session of the Institution of Naval Architects, 12th April, 1878; Admiral Sir R. Spencer Robinson, K.C.B., F.R.S., Vice-President, in the Chair.]

Having been requested to read a Paper giving some account of the now rather celebrated yacht *Sunbeam*, and of the composite system of construction as applied by me to her and other yachts built from my designs, I respond with pleasure.

The *Sunbeam* was built on the Mersey, launched in January, 1874, and I think, judging from her performances since then, she may fairly be considered one of the most successful of the large auxiliary steam yachts—and here I would like to say that without doubt much of that success is due to her able owner, Mr. Brassey, who as a practical yachtsman and navigator cannot be beaten.

It may not be out of place to say a few words as to her origin, because she was the first of the large auxiliary steam yachts. When Mr. Brassey crossed the Atlantic in his steam yacht *Eöthen* in 1872, she as nearly as possible drowned all on board, indeed before getting halfway she clearly demonstrated by her behaviour that she was not the right yacht in the right place—the *Eöthen* was about 340 tons, rather low, particularly so forward, and ill adapted for ocean cruising in bad weather, still she reached New York in safety. Very soon afterwards Mr. Brassey instructed the late celebrated naval architect, Van Deusen, to make him a design for a safe family cruising yacht of about 500 tons, which he did do, and a great beauty the model was; but it proved upon examination to be perfectly unsuitable for Mr. Brassey's purposes, because among other things he required large hold space for sea stores, water, sails, &c., while the design showed an unusually small amount.

Upon Mr. Brassey's return to this country he requested me to make two designs, one of a sailing schooner of 300 tons, and another of an auxiliary screw yacht that would have about an equal amount of accommodation. I at once had models and plans prepared and saw Mr. Brassey, who very soon decided to have the steam yacht idea carried out; the *Sunbeam* is the result, and it is rather gratifying to me to know that after the lapse of four years, she is now as she was built—*i.e.* she has not had spars cut down, ballasting altered, or anything else done with a view to correct faults, nor has she required strengthening in any way.

Mr. Brassey's first idea was to have her built either of iron, or entirely of wood, and fit her with a lifting screw, but I persuaded him to try a composite vessel and a patent feathering screw instead. At that time he had some misgivings about composite

vessels, but he has none now—at least about the *Sunbeam*—for I have heard him say that in the worst of weather she is perfectly staunch, tight, and strong; and so far not the least ill effect has been discovered from galvanic action—indeed when lately examined in dry dock she was found to be practically as good and sound as when built.

Up to the present time I have had one small and six large "composite" yachts built from my specifications, and the curious thing is that the small one was the only one that ever showed the smallest symptom of weakness, and I attribute it to two causes. One being the putting on of an excessively heavy lead keel outside, amounting to one-third of her whole ballast. The other to stupidly leaving off the bilge row of plating although it was specified. After a month or so she began to leak when racing—being of course then hard pressed with canvas—so eventually we hauled her up, took out three planks on each bilge, and put in the bilge row of plating, at the same time adding a number of new bolts in the skin as well as larger ones in place of many that seemed to have worked loose. Afterwards she was quite a different vessel—from this I take it that hardwood planking alone is hardly rigid enough for the bilges, in fact some plating there is almost a necessity.

Regarding the "composite" principle, I have often been asked the question, Why build a "composite" yacht? I answer for many good reasons. As compared with wooden yachts they can be built much stronger and lighter, and when thoroughly well built should be more durable; there is no risk of dry rot in the timbers, and there will be much more accommodation and head room, besides greatly increased stability. Another great matter is that all the ballast can be stowed below the ceiling between the floor plates, so leaving a clear hold for stores, &c., instead of, as is usual, a hold full of kentledge.

Like timber-built yachts they can with perfect safety be sheathed with copper; this, which means freedom from fouling coupled with a more even temperature below, represents the principal advantages wood or composite yachts have over iron ones. There is no difficulty whatever in making a composite yacht perfectly fair and true to the model.

The original intention was to have built the *Sunbeam* to class A1 at Lloyd's, but the Surveyors held out for a dished plate on the top of the wood keel, and other matters of detail that seemed to me of no real value, but rather a useless expense in a yacht. We could not agree, so I then saw the Surveyors of the Liverpool Underwriters' Association, who accepted my suggestions, and offered to give the yacht the highest class in their "Book." I tried to point out to Lloyd's Surveyors that what applied properly to merchant vessels (possibly intended to carry coal or even pig-iron cargoes) could not equally apply to yachts with their small displacements, excessive rise of floor and fine ends. Last year Lloyd's again refused to class a large yacht I had built at Barrow for the Earl of Eglinton—solely because I refused to put the dished keel plate in; she too was transferred to the Liverpool Book, and I am satisfied there is no better yacht in it.

I will now describe as clearly, but in as few words as possible, composite construction as by me applied; and having at present a yacht of 500 tons building to my designs by the well-known firm of Robert Steele and Company, of Greenock, I cannot do better than describe her, because she not only is my latest effort, but is, I trust, an improvement upon the *Sunbeam* of 1874.

This new yacht was given out last November, and I felt rather surprised to learn from the builders a few weeks ago that Lloyd's Surveyor had expressed an opinion that

she could now be classed A1 in their Book. I wrote agreeing to pay the fees; so after a lapse of some years and the loss of several fine yachts, Lloyd's have come round to my way of thinking, in so far as not to insist upon the dished keel plate.

Thinking that a full description of the *Sunbeam* may prove interesting to many, I have had it attached to this Paper, so I will not occupy your time with her, but go to the new vessel, the present condition of which is that the iron work of the hull is nearly all complete, and the planking being fitted. Plate I. represents her midship-section, and Plate II. longitudinal views. She measures 173 feet over all, 152 feet between the perpendiculars, has an extreme beam of 26 feet 3 inches, a moulded depth of 16 feet 6 inches, an extreme draught of 13 feet 6 inches, and her tonnage is just 500. The model represents her accurately, and nothing will please me better than to hear opinions upon it from practical men.

Generally speaking I have been guided by the two Books of Rules for the scantlings, modifying as I considered advisable to suit a yacht. The principal deviation I make is the doing away with the dished keel plate, and substituting two heavy fore-and-aft angle irons. The plate arrangement gives a vast amount of trouble, is a great expense, and, worse than all, it greatly delays the vessel, because the whole has to be fitted upon the wood keel, which has afterwards to be removed to admit of the vertical riveting being done, or else the whole iron structure has to be temporarily supported for riveting and the wood keel fitted up afterwards. With my plan the wood keel is at once laid for good, meantime the centre keelson is being fitted together near the machines, and when ready is put in its place and secured permanently, as there are no vertical rivets in the lower angle irons. These angle irons, you will notice, are wide enough to entirely cover the top of the keel, and that the keel bolts (which are copper-spaced every 18 inches) are clinched on the top. These two bars run well up the dead-woods and stem, and with the heavy deep centre keel plate form a splendid backbone.

For several reasons I make the floors at the middle line about twice the depth required by Lloyd's, and straight on the top. Floor plates shaped as defined by the Rules would be a mistake in a yacht, as the hold would be almost useless, and the ballast would be in the wrong place. With my arrangement of floor plates the whole of the ballast goes in between them, and of course under the ceiling, so leaving a perfectly clear hold with a level floor, and the ballast in the best place for stability. As the floors are so deep I lighten them considerably at the ends of the yacht, but amidships the builder may put them in as much above the Rule in thickness as he pleases, because they act as ballast.

As this yacht will have very heavy masts and great sail power she will have a lead keel of 10 or 12 tons bolted on outside, while inside the ballast will be cast to fit closely, but not allowed to rest on the skin. It will all be well painted, too. The centre vertical keelson plate is continuous, therefore the floor plates are in two pieces, but being extra deep and connected at the centre line by four strong corner angle irons, no doubt they are as good as if solid and in depth as per Rule. My opinion is, that composite yachts should be made strong and rigid about the floors and centre keelson, because the wood keel cannot be counted upon as adding much real strength. I treat it more as a necessity to make the yacht weatherly and to ground her upon.

The frames are of angle iron, as usual; but with the side against the skin increased and made the same width as the moulded flange. This gives a better landing for the planking, and more room to screw up the nuts of the bolts of the outside planking. The

heels of the frames are "set" to land on the centre keelson angle irons, and are held in place by heavy coach screws, going about 5 inches into the solid keel. The frames are double all along the middle of the vessel—say for about 80 feet—extending out to the ends of the floors, but under the engines and boiler they will extend alternately to the floor tops and 'tween deck beams. The inner ends of all these double frames rest on the centre keelson angle irons and have a coach screw like the frames. In the wake of the double frames the outside planking will have extra bolts, and where these frames do occur, the space from edge to edge is only 12 inches, while the landing for the planking is 6 inches wide. The ordinary frames are spaced 18 inches, centre to centre.

The bilge row of plating—indeed, most of the plating—is much above the Rule amidships (besides being treble-riveted at the butts), while at the extreme ends it is less. The sheerstrake is very much heavier than Lloyd's Rule defines, for it will be wounded by side lights, as they go through it. By Rule I think it would be 25 inches × 7-16ths, while I have it 33 × 9-16ths, and bilge-row 39 × 8-16ths, against 16½ inches × 7-16ths. I aim at a very strong vessel, and an extra bit of iron is not costly. Finding that the crosses of diagonal plating from bilge to sheerstrake as defined in the Rule came very much in the way of side lights and other details, instead of them I have a strong arched plate as shown in Plate II. The *Sunbeam* has this arrangement, and is as rigid as can be.

The main-deck beams are full size and of Butterley solid section, with deep-welded knees, and are spaced on alternate frames. The 'tween-deck beams are simply of angle iron, because owing to the fineness of a yacht below water they are rather shorter than the beams above; again, they can be thoroughly stanchioned (which the main deck ones cannot be in a yacht), and they have no cargo to bear. The upper-deck beams have rather a smaller camber than is usual in merchantmen, being nicer to walk upon, and the 'tween-decks are straight. The main-deck beams in yachts cannot always be supported by stanchions in the saloons and other places, but I do put them where they can be got in without interfering materially with the cabins and passages.

The main-deck covering plates for about half the length amidships are much in excess of the Rule—at the ends they are a little less—the gunwale angle iron is stouter, and there will be a strong cross of diagonals at each mast. The 'tween-deck covering plates and beam knee-plates amidships are also above the strict rule. I fancy yachts want to be very strong about the middle, as the displacement, ballast, and power to carry sail are concentrated there; the fine ends of yachts have little to do and seldom give out. According to Lloyd's Rules there should be two hold stringers, but owing to the form of the yacht I only put one, making it stronger than the Rule defines for hold stringer angle iron. As a matter of course the whole of the butts of the outside planking are covered on the inside by a plate the full width of the two planks connected, and extending from frame to frame and riveted thereto.

With regard to water-tight bulkheads, so far I have had them put in in the ordinary way, that is, between double frames, taking care to bolt them extra well to the outside planking. A better, but a more costly plan, perhaps, would be to plate completely the vessel in the wake of each bulkhead, say, for a length of three frames, and rivet the bulkhead thereto—of course the keelsons and stringers form strong supports.

In this yacht, as well as in the *Sunbeam*, and many steam yachts, there is an ordinary open passage through the engine room, connecting the forward and after accommodation; this puts the complete tightness of the bulkheads out of the question,

so it is no use in Lloyd's, or any one else, insisting that the iron bulkheads at each end of the engine and boiler space shall be intact, or that there shall be a large water-tight passage—the latter will not always work, *that* I know from experience—for you must remember that yachts are of comparatively small tonnage, and there is little space to work upon. Again, almost everything has to give way in yachts to cabin arrangements and the comfort of the owner and his friends. I fit strong solid pine doors that would keep a good bit of water out, as I am sure no owner would be bothered with heavy iron doors.

The limber holes are kept about 10 inches above the keel—the reason of this being to get a good solid body of asphalte into the confined spaces, where water from the baths, or from washing 'tween decks, might lodge and do mischief. Lodgement of water should be made impossible, except at the pump wells, in composite vessels. The asphalte will be laid on very hot on the bare wood and iron, and extend above the floor tops. No ceiling will be laid except on the flat of the floor, but the skin where practicable will be quite exposed and open to the air.

The planks of the main deck in large yachts I always make square—in this vessel they will be $3\frac{1}{4}$ inches square—this gives four sides to choose from instead of two, leaving little or no excuse to put a bad side uppermost—of course the beauty of a yacht's deck is everything; however, I question if this plan is much more costly, because it is seldom a plank has to be condemned. In yachts, *through* deck fastenings could not be permitted: even in the waterways I do not put them, because they are not only unsightly but are always liable to leak, causing damage to valuable fittings and annoyance to the owner. Both decks and waterways will be fastened with suitable wood screws put up from below; there will be through clinched horizontal bolts in the waterways, but they will not show at all.

The stern-posts are both of teak as being safer than oak, the dead-woods are fitted as usual, thoroughly through-bolted with copper and in shape to suit the ends of the vessel. All the plank ends at stem and stern-post will be through copper bolted, and you will observe that at each end of the arched binding strakes there are large plates fitted and riveted, taking a secure hold of the lower ends of the vessel.

The whole of the outside planking is of selected hard wood and barely to Rule in thickness, as I really do not think a yacht requires what a heavy carrier does. From the keel to within a couple of feet of the load line it is American elm, above this all teak. She will be sheathed with 22 and 24 ounce copper, which amidships will be carried about 18 inches above the load line gradually rising fore and aft: with the exception of two or three top rows (which will be fastened with galvanized iron) the whole of the planking will be fastened with yellow-metal bolts and nuts. It is important that all bolts be full-sized, very tightly fitted, and absolutely watertight. I never allow a composite yacht to be coppered till she has been tested by water and found absolutely tight all over.

The arrangement of gunwale, waterways and bulwark stanchions I think is a good one, because the covering plate and gunwale angle iron go right round the vessel intact—not a single stanchion goes through. The sketch explains the arrangement. In the wake of all boats' davits I have a strong angle-iron stanchion and knee securely riveted to top strake and covering plates, and to the top of this is riveted the iron through which the davit passes; the whole is cased with an imitation stanchion, but no strain whatever comes on the rail or bulwarks. The bulwarks, rails, stanchions, waterways, and all deck fittings will be of teak.

The very greatest care should always be taken to make the caulking of the skin sound and perfectly tight, and the caulking of the upper deck in a yacht is of vital importance; the seams should be all made one width, and I think the finest marine glue is the best substance to pay decks with. Under the copper there will be two good coats of Stockholm tar, and the skin inside will have a couple of coats of the best bright varnish. As much of the loose iron work as possible will be galvanised, even to the hawse pipes and anchors and chains.

Having now explained roughly the construction of the new yacht, before sitting down I would like to state that my object is always to try and produce a very strong and durable yacht, but at the same time as inexpensive a one as possible. Without doubt the Government system of completely plating over the vessel, and screwing every bolt into and through the plating (*i.e.*, the plating is tapped for the bolts), besides having the nut on the inside, makes a splendid job, but such a vessel must be costly. I find I can now contract for large composite yachts built to the highest grade, and by the best of builders, at no higher cost than wood yachts, and as long as that is the case I cannot understand any one building a large yacht, particularly if for steam, of wood. Indeed, I would much like to hear what any practical man can say against well-constructed composite yachts.

Of course from outside or on deck no stranger will be able to tell that this yacht is not all wood; then again, below, look at the beautiful light appearance the small beams give overhead. I quite omitted to state earlier that the first composite yacht built to my specification was in 1871. She was a yawl of 105 tons, and built for Sir Hickman Bacon, Baronet; and I know from him that she has never shown one symptom of weakness, nor yet has she suffered in any way from the effects of galvanic action. She is as staunch and as sound as can be.

To Messrs. Steele and Co. are due my very best thanks for their kindness in assisting me, not only by lending me their working model, but in sending me the large plans.

SS. YACHT "SUNBEAM."

Built in 1874 by the late Firm of Bowdler, Chaffer & Co., from Designs by St. Clare J. Byrne, Esq., M.I.N.A., of Liverpool, for Thomas Brassey, Esq., M.P.

	Ft.	Ins.
Length over all	181	0
Ditto on load line	154	9
Ditto for tonnage	157	0
Beam extreme	27	6
Depth moulded at mid-section	16	6

	Tons.
Tonnage, O.M., about	565
Ditto Register	334

She was tried officially on the 14th May, 1874, just about all complete and ready to sail, having on board—

	Tons.
Coal	77
Lead ballast	63
Spare gear	6
Fresh water	12
	158

She drew 11′ 10″ forward and 13′ 4″ aft, equal to a mean of 12′ 7″, the displacement at this being 531·4 tons.

Area of immersed mid-section	202 square feet.
Ditto of load water-plane	2,917 „ „
Immersion per inch ... 6·9 tons.	
Midship-section abaft middle of load water-line ...	8·0 feet.
Centre of displacement abaft ditto ditto	2·85 „
Ditto of lateral resistance abaft ditto ditto ...	3·95 „
Ditto of effort of sails (lower plain) ditto ditto ...	5·62 „
Ditto of gravity of displacement below load water-line	3·85 „
Area of lower sails (5)	8,333 square feet.

	Ft.	Ins.
Mizenmast deck, to hounds	68	3
Mizen-topmast, heel to stop	43	0
Mizen-boom, over all	65	0
Mizen-gaff, ditto	38	0
Mainmast, deck to hounds	63	0
Main-topmast, heel to stop	43	0
Main-boom, over all	36	0
Main-gaff, ditto	30	0
Foremast, deck to hounds	57	9
Fore-topmast, heel to stop	43	0
Fore-boom, over all	36	0
Fore-gaff, ditto	30	0
Bowsprit, outside knightheads	24	6
Jibboom, cap to stop	28	0

The *Sunbeam*, until end of 1870, was rigged as a three-masted schooner, with square sails to set flying on foremast; but, to suit her for the voyage round the World, a smaller mizen-topmast was shipped, and standing yards added on foremast.

Machinery consists of a pair of inverted direct-acting surface-condensing engines, of about 70 nominal horse-power, made by Messrs. Laird Brothers, of Birkenhead.

Diameter of high-pressure cylinder	24 inches.
Ditto of low-pressure cylinder	42 „
Length of stroke	21 „
Revolutions of screw, on trial, 95 to 100.	
Pressure of steam on trial	60 pounds.
Mean speed on trial	10·13 knots.

She is fitted with a Bevis' patent feathering screw with two blades, the feathering being worked from inside the vessel through a hollow shaft.

The following statistics are taken from Mr. Brassey's carefully-kept log during his celebrated voyage:—

The total length of the voyage was 35,400 miles; and this the *Sunbeam* accomplished in the wonderful short space of forty-six weeks, out of which one hundred and twelve days were spent in harbours, leaving two hundred and ten days actual steaming and sailing.

The exact figures are—under steam alone 14,979 miles, and under canvas alone 20,396.

The best day's run under steam alone was 230 knots, and under sail alone 299 knots, while the most successful continuous steaming was from Penang to Galle, in the week ending 5th April, when she steamed 1,451 knots straight on end, with a daily consumption of $4\frac{1}{4}$ tons of coal. The highest speed ever attained under canvas alone was 15 knots, in a squall in the North Pacific. Mr. Brassey adds that the bunkers hold 80 tons of coal, and that her average consumption of fuel in fine weather is 4 tons per twenty-four hours.

The model in the room is of a new yacht, a few tons less than the *Sunbeam*, but very like her; indeed the only difference is that the new vessel is a shade fuller in the ends, and consequently has a longer floor. Height out of the water, draught of water, and outline below are almost the same as the *Sunbeam*.

DISCUSSION ON THE TWO PRECEDING PAPERS.

Mr. Thomas Brassey, M.P. (Associate): Sir, I wish to take this public opportunity of expressing my grateful thanks to Mr. Byrne for having prepared the very admirable design for the *Sunbeam*. I am afraid the model is not shown to great advantage on the wall; the top light, which exhibits these beautiful pictures to very great advantage, does not show the models equally well. So much is the under-water part of the model in shadow that it is difficult to appreciate the merit of the design as we see it in this room. With regard to the model of the *Sunbeam*, I have to say that the one fault, and not a very great fault, but still to some extent a fault, and we ascertained its existence, was that the vessel was rather too fine abaft the mizen rigging. I am not in the market, I have no desire to sell the *Sunbeam*, therefore I can speak rather more frankly on the subject than under other circumstances. The advantages of the model were very great. The *Sunbeam* was admirably dry forward, took the sea with very easy motion, was remarkably stiff under sail, and I feel confident, with the staysail aweather, properly handled, might be trusted to go in safety through the most severe weather which we may expect to encounter at sea. Another merit—I do not speak as a naval architect, but from practical experience of the model—was this, it presented a remarkably round side. I believe the middle body of the *Sunbeam* is unusually short. Mr. Byrne is more competent to inform you upon the subject than I am, but I believe it is so; and though, as I say, I do not speak as a naval architect, yet the impression that I have derived from the perusal of the admirable work recently published by Mr. White leads me to the conclusion that in the length of entrance and length of run, combined with short middle body, I see an explanation of the fact that the *Sunbeam* was remarkably fast in light winds, and steamed with an exceedingly small consumption of coal—going about 220 knots a day, with a consumption of 4 tons—and that under steam she was remarkable for handiness. All these are qualities very much to be desired, and I believe the model adopted by Mr. Byrne tends to produce those very desirable results. As we are here discussing the construction of yachts, I would venture to submit to this Association the idea of introducing, if it be

possible, the system of water-jet propulsion somewhat more extensively in yachts. It may be that the method of propulsion is not so economical in regard to consumption of coal, but economy in consumption of coal is not the first consideration in the designing of yachts. On the other hand the combination of adequate steaming power with good sailing qualities is a great desideratum in a yacht; and there can be no doubt that the system of water-jet propulsion does afford a very valuable solution of that problem. I should be very glad if the idea of water-jet propulsion were studied a little more than it has been by the designers of yachts, and I think I may say that it ought to be an object with yacht owners to promote experiments which have any promise whatever in them, and it being the case that water-jet propulsion is at the present time in an experimental stage, having considerable promise in it, I think that consideration should weigh with yacht owners who are contemplating the designing of new vessels. The rig of the *Sunbeam* was somewhat peculiar; it was suggested by Mr. Lapthorn, of Cowes, the peculiar feature being that the mizen was the largest sail. The *Sunbeam* was a three-masted fore-and-aft schooner, the mizen being the largest sail, and the mainsail an intermediate size between the foresail and the mizen. The object which Mr. Lapthorne had in view was that of combining steam with sail, and while under steam making it possible to keep the largest sail set, and doing useful work. In our case we rarely found that sail and steam could be combined with advantage. I am so great a lover of sailing, that whenever there is wind enough to make the sails a valuable auxiliary to the steam, I am apt to cease steaming altogether, and rely entirely upon sail. The advantage of that rig was this, that in going on a wind, having a large mizen, you have a valuable driving sail, and can ply to windward to greater advantage. There was also considerable advantage in the facility with which the evolution of tacking could be performed, involving very little trouble and labour to the crew. On the other hand, Sir, you, as a sailor, will quite appreciate the disadvantage of that system of rig when going large with a strong breeze; you are naturally obliged to reef the mizen, when, had the larger sail been more in the body of the ship, it would not have been necessary to reef, and you would have been able to profit by the full spread of canvas. I did make some modification in the rig of the *Sunbeam* before sailing on our voyage of circumnavigation; I adopted a square rig for the foremast; and I think, in a vessel of the considerable size of the *Sunbeam*, that square fore-top sail and top-gallant sail would always be a desideratum. I have not had much to criticise in the design of the *Sunbeam*, and I consider that the success achieved by Mr. Byrne does him credit, and that what he has done in the *Sunbeam* and the sister vessel is really very creditable to the yacht-building community in this country.

Mr. Benjamin Martell (Member of Council): I should like to make a few remarks, Sir, if you will allow me, with reference to this Paper of Mr. Byrne's. I should not think it necessary to make any remark whatever if the Paper had contained merely what has been read by Mr. Byrne; but, seeing other matter in the Paper, which will go forth to the public, I think I should make a few remarks on some of the assertions here. I quite agree with Mr. Byrne on the general principle of the composite method of construction. No doubt it is a very beautiful system, particularly for yachts. I often think it is a great pity the system of construction is so expensive that we cannot entirely do away with wooden shipbuilding, and adopt this instead. I only agree with this when, of course, the scantlings are of proper dimensions; and so long as Mr. Byrne adheres to the scantlings that have been framed for the construction of these vessels he cannot go far wrong, because they have been ascertained from actual experience to be what is necessary to produce a good and efficient vessel; and of all the vessels built on this construction, I have never known a single one show any symptoms of weakness. But Mr. Byrne says he deviates from it in one particular, and that particular is that he does away with a flat plate *here*, and substitutes two angle irons. He does not say he would do that if he had to design cargo-carrying ships, but he does that in yachts, because a yacht does not carry a cargo such as coal or pig-iron, and does not require so much strength. But, unfortunately, one of Mr. Byrne's yachts came to grief, and that was owing, he says, to carrying a large amount of lead outside. Now it seems to me it does not matter whether you carry cargo inside, or whether you put weight outside. If it tends to cause straining to the vessel at that part—the garboard seam of the vessel—you require the same kind of strengthening to prevent the straining; and I can only express my regret, on the part of the owner of that ship, seeing the very considerable expense he was put to afterwards, that Mr. Byrne did not adopt the dish-plate keel* and the bilge plate, which he had to do eventually, which is required by Lloyd's Rules, which no doubt

* Mr. Martell is in error in stating that the "dished keel plate" was eventually put in—the bilge plate was, but it only.—St. C. J. B.

would have prevented this great straining, and prevented the great expense to which the owner was put. I should finish here, but in the next place there is a very unpleasant paragraph in this Paper, which I dislike very much, and I must say a few words with respect to that. It has not been read, and if you will allow me I will read it. Mr. Byrne states that he is now building a new yacht similar to the *Sunbeam*, but he trusts an improvement. He says, "This new yacht was given out last November, and I "felt rather surprised to learn from the builders, a few weeks ago, that Lloyd's Surveyor had expressed "an opinion that she could now be classed A 1 in their book. I wrote, agreeing to pay the fees; so after "a lapse of some years, and the loss of several fine yachts, Lloyd's have come round to my way of "thinking, in so far as not to insist upon the dished keel plate." Previous to this he says that this yacht was designed in November, and this suggestion from Lloyd's Surveyor came to his notice in January or February, or something like a few weeks ago. That seems to me to be a very invidious reflection upon Lloyd's Registry and their Surveyor, that they should come round to him some months after this vessel had been designed and say, on his agreeing to pay the fees, they would agree to class her. A great number here who know Lloyd's Registry, will know, I am sure, that any question of fees did not influence them in classing this vessel, and such insinuations are strongly to be deprecated.

Mr. William Denny (Member of Council): There is only one point in the construction of the *Sunbeam* on which I wish to speak, and it is because this point may be developed further in vessels of quite a different class—I mean that bow stringer which extends from the stem forward up to the deck amidships, and down to the keel aft. I daresay that stringer prevents racking in the frames, but I question very much if it performs the functions that the designer of it intended it to perform. Upon the sheer plan it looks as though it would perform the functions of a bow girder, but if any one will look at the model he will see that it could not do so. About six or seven years ago my firm built for the Danube several light-draught steamers. We did not design those steamers, and therefore claim no credit on that point. We received designs from the Danube for them. There was a bow girder in their design, but it was a real bow girder, and for two reasons, first of all because the steamer had no form—she was a long straight-sided steamer, and the consequence was the girder had a direct line of action—and secondly because these were iron steamers, and the girder was placed inside of short reverse angles on the frames, we had then the opportunity of placing angle iron on each edge of the girder, which added cross-section for rigidity. This was effective. I think its usefulness was exaggerated, but still there it was. I do not think that Mr. Byrne's bow stringer or bow girder could fulfil the functions that it would appear to fulfil upon that section, and which the model controverts.

Mr. J. A. Welch (Member): I should like to make one observation upon Mr. Byrne's plan. I do not consider myself that a perfect composite vessel is built unless she is built so as to be wholly rigid independently of any planking put on, especially when it is a single plank as is shown on that section. Mr. Martell alluded to the dish-keel. I have built many of those composite ships, and therefore know what he means; but we carried the dish-like keel up to the stem-head, and we formed a stern timber that came down on a water-tight flat that went over the screw shaft, and also had a stuffing-box bulkhead fitted. We also put in a bulkhead forward for a collision bulkhead, and thereby increased the safety, whether you receive injury in the wake of the screw-propeller, or whether you run into anything. I will not allude to the bulkheads spoken about, but I merely want to observe that unless that system is carried out so that when you put the skin on there should be no strain whatever, it is not a perfect composite vessel, however it may be arranged or constructed. Another point is the mode of fastening—you are necessarily obliged to have short fastenings. In the Government Service for many years we have always tapped the frames. I do not understand from this Paper that that has been the case here, but I have found it a very good plan for a single-skin vessel. The expense is nothing as compared with the efficiency of the fastening, because if there is one point which a composite vessel is deficient in it is the fastenings. That is all on that subject, Now I want to allude to Mr. Harvey's Paper. I think after a gentleman takes the trouble to collect facts. as he must have done, to produce that Paper, it would be a pity that it should be passed without some remark, and as no one has at present made any observations on it, I venture to do so, as I have some knowledge of the vessels he has put on his diagrams. I have seen those vessels on many occasions during their construction and since. I sailed in the *Rose of Devon* in a match at Plymouth when she won a cup, and therefore I know something of her. As to the *Sea Belle*, of which I see the model here, I superintended her construction, the plan having been referred to me to report on, and a very successful plan it is for lightness and strength. It is a double skin something similar to what we have in the Navy

for composite building. The first thing that strikes one on looking at those diagrams is the novelty, the lightness, that that vessel the *Jullanàr* presents compared with anything else. The chief feature, looking at it from our point of view as naval architects, is the long length of water-line and extremely short length of keel; but not that alone—she has attained a great measure of her success by being a very fast vessel, a very handy vessel, and she is reported, as far as I have learnt, as being a very good sea boat. But that is not the novelty to which I wanted more particularly to allude. Looking at the section we will trace her metacentric height—her metacentre is low—it is below the water-line. I have had no experience of that. I have had to do with designing many of the Government cruisers, and among the very great variety I have dealt with I never had a metacentric height anything approaching that position. The heights ranged something in this way: we had between the metacentre and the centre of buoyancy always about from 3 feet to 6 feet according to the style and size of vessel, and we also had from 1 foot to 3 feet for the metacentre to be above the water-line. When you see this below the water it appears almost startling, but it is easily accounted for when you take into consideration the vessels to which I allude: they are vessels of the proportion of length to beam of $3\frac{1}{2}$ to 1. The *Rose of Devon*, the shortest yacht put upon the diagram, is about 4 to 1. But when I look at the *Jullanàr* and find that she is a vessel of nearly 6 to 1, I then begin to see some reason for what she has attained when I take into consideration all the circumstances, one of those being that she requires 81 tons of lead to be incorporated in the build, or as ballast, in order to give her the same sort of sail power (for I assume that they are got out proportionately, so that there is a proper ratio in the sail power of each of those vessels to their stability): but there are 81 tons of lead in the *Jullanàr*, as compared to 57 of iron in the *Rose of Devon*. When you look at the sections, if you trace the section of the *Rose of Devon*, she is really a very nicely formed vessel, and as for length, this length of 4 to 1 is a very good proportion for sea-going qualities. The principal object I have in view in speaking on this subject is to call attention to it as a continuation of what was remarked here two years ago, when displacement was considered as the proper measure of the relative values of those vessels. Now, if displacement were taken as the measure of those vessels, we should get rid of an anomaly that exists with respect to this, for I find that the *Rose of Devon* is 148 tons, B.M., and she is only 128 tons of displacement. That, from my point of view in vessels which I have constructed, is a comparatively fine vessel, measured in that way; but when you look at the *Jullanàr*, and find she has such a small tonnage as 127 tons, B.M., and so great a displacement as 156 tons, of course you can see how the displacement is swallowed up by this great weight. But what I want to say is, that if we had a basis in the way of displacement for comparing those various vessels, we should get to a truer mode of comparison, and not have those anomalies, and should come back to something like this, that we need not go further in the way of that vessel, the *Jullanàr*, because, although great credit is due to Mr. Harvey for having achieved it both in form and ballasting, and every other thing which he has used—for the test of merit is success after all, and she has made her mark—I say that for yacht construction we, as naval architects, ought not to proceed in this track, but ought to take up that form of body that we have been called on to admire from childhood. That is to be done in giving proportion at a less rate. I am glad to hear Mr. Harvey say that he took the *Miranda's* proportion as being more the proportion for a sea-going vessel. Her proportion is $4\frac{1}{2}$ to 1, and that comes more within the scope of my remarks.

Mr. William Henry White (Member of Council): I should like to say one word, as I have been alluded to in Mr. Harvey's Paper. May I ask Mr. Harvey if he could, without any breach of confidence, add the particulars of the forms of those vessels to the information given by those curves, which are very interesting as far as they go, but which certainly do not convey much idea to my mind of relation between the fore and the after bodies of those yachts? We have curves constructed on a particular mode, which I have never seen used before, and neither do I find any reason in the Paper why it should be done now. An ordinary naval architect would be able to see the form of the vessel better if he had the ordinary plans. Some of Mr. Harvey's terms are novel; but his meaning I think on careful study can be understood, and is much the same as is conveyed in ordinary terms. I am not acquainted with the use of the term "metacentric air-box" in any published work on stability; and I do not know whether it is needful to use the term "artificial or natural stability." I do not wish to quarrel with him on that; but I wish to say, as one who has endeavoured, and I am sorry to say unsuccessfully, to analyse the causes of superiority of some yachts that have done well, that if Mr. Harvey could give us the actual forms of those vessels, and more than that, their sail power, I should be obliged; because

though we have had such refinements of comparison with regard to the position of the centre of gravity of the various water-line sections, we have not had a word about the actual distribution and quantity of sail, and the position of the masts, and things of that kind, which I think are of the greatest importance. The point to which Mr. Welch alluded, as to the position of the metacentre in relation to the water-line, I think he answered himself. If you adopt such proportions as to bring the metacentre well down, and you want to get stiffness, you must put in ballast.

Mr. Henry Liggins (Associate): Mr. Chairman, I wish to say a thousand things in three words, but I am afraid I shall not succeed. It is well known that Mr. Harvey is one of the most eminent yacht builders in the world. Thirty years ago he produced the fastest vessel, the *Volante*. The *Rose of Devon* is a very fine vessel—so is the *Sea Belle*, and so is the *Miranda*. Now we come to the last, the *Jullanàr*: this is her model, and it is I daresay well known to many of you; I wish to point out that in my humble judgment the *Jullanàr* is a very great failure. I do not deny that she can win cup after cup, as I saw it done. I saw her the first day she raced; but I contend that racing machines are not fine yachts. I want a minute or two to show you that that vessel is not a fine vessel in form, and not one that ought to commend itself to naval architects to admire and approve. The length and breadth of this vessel is something like, roughly, a 200-ton schooner yacht. That vessel races I believe at 128 tons, and therefore that she should win a cup against a faster vessel of 200 tons by reason of a time allowance is not to be wondered at. Now how does she get that? By what is called cheating the tonnage. Who first introduced that system of cheating the tonnage? A very eminent gentleman in this room, the late Mr. Ditchburn, told us here that he thought out the raking stern-post with a view to a large vessel winning on a small racing tonnage—that was the *Mosquito*—thirty years ago. What are you to do? You are to take the length of your deck from the fore part of the stem to the after part of the stern-post, and measure that yacht for racing.

Mr. John Harvey (Member): No, no.

Mr. Liggins. Then the rule is departed from by which yachts are measured.

Mr. Dixon Kemp (Associate): In this particular case she was measured on the water-line.

Mr. Liggins: Then the vessel, measured by the plan adopted and arranged for that particular vessel, of which I was not aware, clearly is altered in some of its elements, because the greatest breadth and the greatest length of that vessel is very much like the *Cambria*, say of 188 tons. I remember measuring the *Cambria*, officially, for her racing. She came out about 188 tons, and the dimensions of this vessel are about the same. The stability of this yacht is produced in a great measure by an enormous amount of extra work in the keel and lead ballast outside. What sort of a vessel for practical purposes is that? It clearly stamps this vessel as a racing machine, and as such it ought not to be entitled to our admiration. I will not venture to intrude myself further—I could say a great deal more.

Mr. St. Clare John Byrne (Member): Mr. Chairman, Mr. Martell took me to task for one or two things, and I should like to say a few words in reply. First of all, I wish to explain that my whole Paper had allusion to yachts and nothing else. I have built one composite trading vessel, and that vessel I did put the keel plate in that I do not put in yachts. Mr. Martell said that the frames were above the scantling. Mr. Martell is wrong. The frames are below the scantling required by Lloyd's.

Mr. Martell: I beg your pardon.

Mr. Byrne: And to oblige Lloyd's the bilge-kelson is increased half an inch to make up for reduction of the frame. I think if that is inquired into Mr. Martell will find I am right. The frames are below Lloyd's actual requirements, and the bilge-kelson was increased half an inch to meet Lloyd's requirements to get the class, at least that is what Mr. Robertson told me.

The Chairman (Admiral Sir R. Spencer Robinson, K.C.B., F.R.S., Vice-President): Mr. Byrne, I think this is an Institution of naval architects and marine engineers, for the purpose of discussing scientific questions which shall be of benefit to the professions that the Institution represents; and I am afraid that entering into these personal questions, which often arise from simple misunderstanding and which are difficult to solve, even when they do arise from simple misunderstanding, may probably lead to some irritation, and that feeling which is not at all conducive to the scientific object for which we have met here together. I think it would be well if this subject were allowed to drop. I have only one thing more to do, and that is to ask Mr. Harvey to answer the questions put by Mr. White, as briefly and as free from personalities as possible, because, after all, our object is science. I am very sorry if I have been obliged rather to curtail the reading of Mr. Harvey's Paper, and to ask gentlemen to be as short

as possible in the observations they made upon both these Papers, but really our time is not our own, and it is far past the usual hour of these Meetings.

Mr. HARVEY: With respect to the remarks made by Mr. Welch, he must not suppose that I represent the *Miranda* or *Sea Belle* model before you as the best sea-going boat. I put the *Jullandur* before you as the best sea-going boat. Mr. White's humorous remarks on my Paper are somewhat encouraging, and if he finds as he intimates, that there is something in it when understood, it will somewhat excuse my unscientifically describing any portion of a diagram as the "metacentric air-box." If Mr. White thinks the drawings of the boats illustrated worth his notice, I shall have great pleasure privately to show them to him; I may at the same time add that sail plans and the results of the calculations accompanied each of the models exhibited at the Shipwrights' Exhibition. I beg to thank you for the pleasant manner you have listened to one who does not pretend to be in the least a lecturer.

The CHAIRMAN: I should only propose, as a conclusion of our proceedings, that these two gentlemen receive your thanks for the interesting Papers they have written.

ON THE USE OF STEEL FOR MARINE BOILERS, AND SOME RECENT IMPROVEMENTS IN THEIR CONSTRUCTION.

By W. Parker, Esq., Chief Engineer Surveyor of Lloyd's Register, Member.

[Read at the Nineteenth Session of the Institution of Naval Architects, 12th April, 1878; John Scott Russell, Esq., F.R.S., Vice-President, in the Chair.]

During the last few years several important improvements have been made in the details of marine engines and boilers by which the wear and tear has been lessened and the durability increased. The pressures meanwhile have been slowly but steadily advancing from 60 pounds to 75 pounds, now a common pressure, and in a few instances 90 pounds has been reached. These gradual increases have also, I am assured by those engaged in working the steamers, been attended with a marked economy. But up to the present time all attempts that have been made with new forms of boilers, with the view of obtaining still greater pressures, have uniformly been signal failures, and a vast amount of money has been swallowed up in extensive experiments bearing on this point. To prove this I need only mention the names of the steamers *Marc Antony*, *Fairy Dell*, *Malta*, *Montana*, *Dakota*, and *Howard*, the boilers of which were constructed to work at a pressure of not less than 130 pounds per square inch. The recent adoption of mild steel for marine boiler making, however, will enable the present form of boiler to be made of greater strength, and gives promise of further advancement in the direction of higher pressures; and if experience is satisfactory as regards the comparative durability of steel and iron boilers it may not unreasonably be expected that this material will become almost universally used for their construction.

Some months ago the employment of steel for such purposes was ventured on by only one or two firms, but it is now coming into more general use; and at the present time there are about 27 marine boilers being constructed of this material, under the inspection of the Engineer Surveyors to Lloyd's Register, with reductions in the scantlings of the shells and stays to the extent of about 25 per cent. In the first few sets of these boilers it was deemed advisable to submit the material to some severe tests. Pieces taken from the shell and front plates were subjected to tensile tests, and the mean of the results of over 80 tests gave a tensile strength of 27·5 tons per square inch, while the extreme variations of strength in the different plates, manufactured by different companies, and on different processes, was not more than 4 tons per square inch. Shearings of every plate used in the construction of the furnaces and combustion chambers were subjected to a tempering test; they were made red hot, quenched in water and bent cold almost double, with satisfactory results in each instance. In order to prove that the material does not suffer from the effects of repeated heating and cooling, I had two pieces of plate made hot and quenched in water repeatedly—one

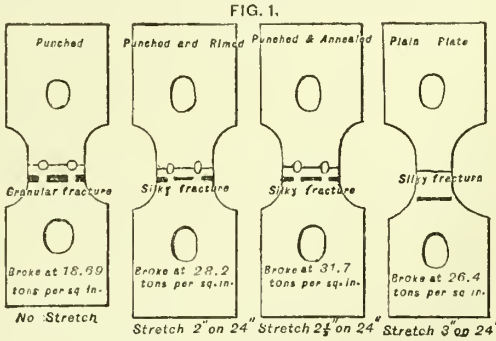
50 times and the second one 100 times, but without any apparent injurious effect upon the temper of the material, the specimens so treated bending almost double without fracture, as may be seen from the specimen produced; further, one of these pieces has been tested, and its tensile strength has been found to be fully equal to the original plate. Specimens of the longitudinal riveted seams were also pulled asunder and their actual strength ascertained. Boxes constructed to fairly represent the back-water spaces of the boilers were made of steel and iron and tested by hydraulic pressure to destruction.

These experiments, which were not confined to steel manufactured on any particular process, and the results of which approximated so closely to each other, afforded pretty conclusive evidence of the fact that the improvements recently effected in the mode of manufacturing mild steel have ensured the production of a material which, by its uniformity of tensile strength and ductility, &c., is eminently suited for all the purposes of marine boiler-making; and the satisfactory nature of these tests and the information gained thereby have enabled us to dispense with many of them in subsequent cases, the actual tests now required being much less stringent.

While this steel possesses such excellent qualities, however, it has been shown on several occasions that some of its essential qualities are liable to be injured to a much greater comparative extent than in iron by the operations usually occurring in boiler-making. For example, a great loss arises from punching when special treatment is not subsequently employed; it has been shown that this injury is to some extent proportional to the thickness of the plates and varies with the relative sizes of punch and die. In three series of experiments I lately conducted on steel boiler plates, the loss from this cause in some instances rose in $\frac{3}{4}$-inch plates as high as one-third of their ultimate strength, and in this respect these experiments agree with others previously made on plates of a similar thickness. The loss in thinner plates was found to be for $\frac{3}{8}$-inch plates 18 per cent., for $\frac{1}{2}$-inch plates 26 per cent., and for $\frac{5}{8}$-inch plates 33 per cent. In order to arrive as nearly as possible at a practical result these specimens were prepared so as to represent the pitch and diameter of rivet holes occurring in practice.

Four of these specimens which were cut from the same plate are shown on Fig. 1, from which it will be observed that the plain piece broke at a strain of 26·4 tons per square inch with a fine silky fracture; the punched piece broke at 18·69 tons per square inch with no appreciable elongation and with an uniformly crystalline fracture; the specimen that had been rimed out after punching broke at 28·2 tons per square inch with an elongation of 2 inches in 24; while the piece that had been annealed after punching stood 31·71 tons per square inch and stretched considerably. The results of the tests on the other specimens were practically identical. The diminution in the strength caused by punching was thus 28·7 per cent. in comparison with the plain plate, while it is considerably more if we compare it with the rimed or annealed plate. The drilled specimens in each series stood as much as the solid plate, and in one or two instances there was even a perceptible gain in the strength of the drilled specimen.

FIG. 1.



The effect of punching in these specimens was not only to cause them to break

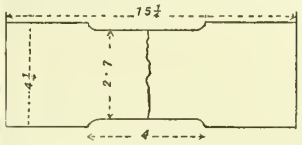
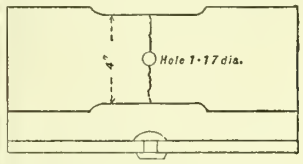
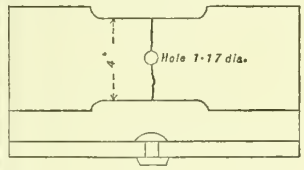
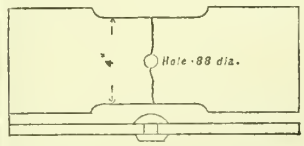
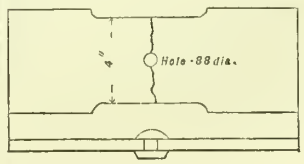
at a less tensile strain, but it also prevented the specimens from stretching, causing them in fact to break with a crystalline fracture. This at first sight would seem to indicate that the quality of the material had been deteriorated from hole to hole. It is not so, however, as these experiments show, and in this they confirm results previously obtained with material of a similar description. They clearly prove that the injury is confined to a zone of metal round the hole less than $\frac{1}{8}$ of an inch thick; for when $\frac{7}{8}$-inch holes were punched and then rimed out to $1\frac{1}{8}$-inch diameter the material stood as high a tensile strain as the plain specimen. It has been shown by careful experiments that in the process of punching steel plates, the temper of the material becomes altered for a short distance round the hole, the metal becoming harder and less capable of stretching. Owing to its hardness and inability to stretch, this part round the holes when the piece is under tension takes a higher proportion of the strain than the other more yielding parts, and hence it reaches the breaking strain sooner. When the part round the hole gives way its strain is transferred to the other parts, and at first the extra strain falls suddenly on the adjoining parts, and this intense local strain apparently sets up a tearing action across the whole section of the plate, causing it to break at a low strain without stretch and with a crystalline appearance. As the loss from punching is so much greater in steel than in iron plates above a certain thickness, it is desirable to reduce this loss so far as may be practicable. Punching the holes small and then riming them, or drilling the holes entirely, or annealing the plates after ordinary punching may be resorted to for maintaining the strength of the material in the structure. It also occurred to me that the hot rivet cooling in the punched hole might have the effect of annealing the disturbed part round the hole and restoring it to its normal condition, and in order to ascertain this I had a series of experiments made with steel plates $\frac{3}{4}$-inch and $\frac{7}{16}$-inch thick. The results of these are given in Table A, from which it will be seen that the cooling of the rivet did not affect the $\frac{3}{4}$-inch plates, whilst the strength of the $\frac{7}{16}$-inch plates was increased 1·8 tons per square inch.

Another operation which injures steel to a greater comparative degree than iron is flanging, and it is necessary in order to overcome the effects of this process to have the plates that are flanged subsequently annealed. If this precaution be not taken it will probably be found that after the work is completed the plates will crack, and this circumstance has given rise to many surmises as to the cause of the apparently "mysterious" fractures that have been found in some steel plates. In conducting the operation of flanging with ordinary boiler-maker's plant it becomes necessary to heat the plates locally, the effect of which is to induce in the vicinity of the heated parts a state of initial stress which in steel is much more severe than in iron. The annealing is sufficient, however, to set at rest all the disturbed particles, to relieve these strains, and thus restore the material to its normal condition.

It would thus seem that greater care and attention *must* be exercised in the manipulation of this material than with iron, and that, while it is possible with careful treatment and proper appliances to practically maintain the original strength of the plates in the structure, the difference between the two materials and the consequent different manipulation required in each case must be realised, not only by the manager, but by the men who have to work the metal, for steel is much more liable than iron to be injured by the heavy usage to which materials are subjected in the ordinary boiler yard. This it seems to me is a point upon which we cannot be too emphatic. When it happens that in consequence of improper or careless manipulations unsatisfactory and unlooked-

Table A.

Table of Tests taken in Dead-weight Lever Machine at Messrs. Charles Cammell & Co., Sheffield, to show the annealing effect of a hot rivet in an ordinary punched hole, Plates $\frac{3}{4}$ inch and $\frac{7}{16}$ inch thick.

Description. Sub-carbonized Steel Plates.	Thickness.	Description.	Breaking Strain in Tons per Square Inch.	Elongation per Cent.	Reduction of Area per Cent.	Remarks.
No. 1	$\frac{3}{4}$ in.	Plain Piece	27·125	28·125	38·85	 Silky Fracture.
No. 2	$\frac{3}{4}$ in.	Hole Punched	21·605	34·82	16·66	Crystalline Fracture.
No. 3	$\frac{3}{4}$ in.	Punched Hole Hot Rivet Riveted in with large Head	20·591	12·38	21·70	 Hot Rivet with large Head. Crystalline Fracture.
No. 4	$\frac{3}{4}$ in.	Ditto	22·853	34·80	21·36	 Hot Rivet with large Head. Crystalline Fracture.
No. 1	$\frac{7}{16}$ in.	Plain Piece	27·292	30·25 (in 4 in.)	51·36	Silky Fracture.
No. 2	$\frac{7}{16}$ in.	Hole Punched	25·123	54·11	30·25	Silky Fracture.
No. 3	$\frac{7}{16}$ in.	Hole Punched Hot Rivet Riveted in with large Head	26·798	44·70	14·80	 Hot Rivet with large Head. Silky Fracture.
No. 4	$\frac{7}{16}$ in.	Ditto	27·141	24·70	17·30	 Hot Rivet with large Head. Crystalline Fracture.

for results are obtained, and preconceived notions are somewhat rudely shaken, it not unusually occurs that in trying to unravel the cause of the mishap attention is almost wholly confined to the composition of the metal, and little or no heed is paid to the manner of working it. Conclusions arrived at under such circumstances, being based upon a misconception of the actual facts of the case, might tend to throw unjust suspicion upon steel, and greatly hinder its more general introduction for marine boiler making, and it is, therefore, incumbent on us to discriminate in such cases as far as may be possible between what is owing to the quality of the material, and what is simply the natural consequences of an absence of a due appreciation of the peculiar properties of mild steel.*

With regard to steel rivets, I may state that in all the boilers to which reference has been made at the beginning of this Paper the rivets used are steel. It appears that if care is taken to heat them uniformly and not to overheat them, they may be used with as much reliability as iron rivets (I refer to rivets up to $1\frac{1}{8}''$ diameter). The experiments made on the riveted seams of these boilers have, however, disclosed the fact that the bar-steel at present supplied for rivets is not of so uniform a character as the plates of the same material; for while in one instance the rivets sheared at 27 tons per square inch, in another joint similarly proportioned the shearing strength was found to be not more than 19 tons. This wide discrepancy in the quality of material supplied from the same manufactory, and which had been thought to be of a uniform character, is somewhat startling, and demands a full explanation. The matter is one which primarily concerns the steel manufacturers and it is now engaging the attention of some of the Companies. When these investigations have been concluded we shall no doubt be in a position to place as much reliance on the shearing strength of rivet steel as we now do on the tensile strength of steel plates; but in the meantime until we are reassured on this head it is desirable to ascertain by actual test the quality of the rivets employed, and this is done in each instance in the boilers now in course of construction.

The experiments on riveted seams have also shown that if double-riveted joints are made of steel with the same ratio of bearing surface to area of plate as is usual with iron, there is a likelihood of the plate giving way by crippling or upsetting behind the rivets, causing the holes to stretch oval and the joints to open at a very low strain compared with the ultimate strength of the material. So that a pressure of little more than twice that at which the boiler is designed to work, or say one-third of the bursting strength, would cause the boiler to leak. It will therefore be found necessary in proportioning steel joints to allow a greater amount of bearing area than would be done in iron joints.

The only important point in connection with this subject regarding which we have scarcely any reliable data, is the question of the comparative corrosion in steel and

* I may here give a practical illustration bearing on this point which came under my observation this morning. In a letter from one of our Engineer Surveyors he reports the unexpected fracture of two furnace plates in steel boilers being constructed under his inspection. It appears that the furnaces were not exactly the same diameter as the front plates in which they were intended to be riveted, and that they had been drawn and hammered to make them come in. The riveting of the front seam of the furnaces was little more than half finished, and was being proceeded with when the plates in both cases cracked from the rivet holes for a distance of about $8\frac{1}{2}$ inches, at a considerable distance from the part then being riveted. The material was not of a brittle nature. A specimen tested showed a tensile strength of 27·6 tons per square inch, and the tempering and bending tests were also satisfactory, cuttings from these two plates having doubled to $\frac{7}{8}$ without any appearance of fracture. This result proves that although such treatment may to a certain extent be admissible in the case of iron boilers, it must be avoided in the case of steel.

iron marine boilers, and although the analytical experiments that are now going forward on a small scale may furnish some interesting particulars it seems probable that we shall have to wait for the disclosures of actual experience. On a recent occasion when I had an opportunity of examining the boilers of two vessels fitted with steel and iron boilers working under the same conditions, the steel boilers had apparently suffered more than the iron. In the steel boiler ten years old it was observed that the corrosion had been most capricious in its action, and the effects on contiguous plates which were to all appearance subject to precisely similar conditions were very different. The corrosion also seemed to be very severe in the narrow water spaces in which, from the defective circulation, the water would at times be driven from the surface of the plates. By the courtesy of the superintendent engineer of one of these steamers I was enabled to have a specimen cut from two plates which showed vastly different results so far as regards corrosion; but upon being analysed they were found to be pretty nearly alike in their constituent elements, the slight variation not being more than would probably occur in plates from the same ingot. The per-centage of carbon was very much higher than is usual in plates manufactured at the present time, and judging from the analysis the original strength of the material could not have been much short of 40 tons per square inch. Table B gives the analysis referred to which was repeated by three different chemists and showed practically the same result.

TABLE B.

Analysis of Two Plates contiguous to each other in a Steel Boiler working under identical conditions, and which showed very different results as regards Corrosion.

PER-CENTAGE COMPOSITION.	This Plate badly corroded. No. 1.	This Plate in good condition. No. 2.
Combined Carbon	0·41	0·40
Graphite	none	none
Silicon	trace	trace
Manganese	0·25	0·25
Sulphur	0·05	0·06
Phosphorus	0·02	0·02
Iron (by diff.)	99·27	99·27
	100·00	100·00

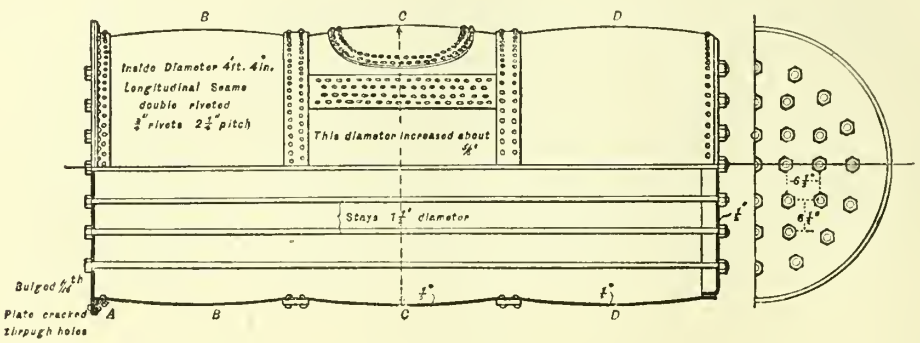
It is only right to remind you, however, that at the time when the boilers in question were made the manufacture of mild steel had not advanced to such a state of perfection as has since been reached, and it would therefore be unsafe to accept these results as a criterion of the effects of corrosion on the steel of the present day.

With regard to the corrosion of shells I think it is to be regretted that the

longitudinal seams in shells are not made with double butt straps, as if this were done, and the inner strap and rivet heads were made of extra dimensions, a uniform corrosion over the entire shell to the extent of say about 30 per cent. would still leave the structure at its original strength, *viz.*, that due to the strength of the longitudinal seam.

Through the kindness of Mr. W. Dean, Locomotive Superintendent of the Great Western Railway Company, I lately had an opportunity of witnessing at Swindon an attempt to burst an experimental steel boiler, representing the barrel of a locomotive as shown on Fig. 2. The internal diameter of this boiler was 4 feet 4 inches; it

FIG. 2.



was made of $\frac{1}{2}$-inch plates double riveted with $\frac{3}{4}$-inch rivets, $2\frac{1}{4}$-inch pitch, the joints being double butt-strapped, and the workmanship extremely good. At a pressure of 728 pounds per square inch the end plate cracked between the rivet holes for a considerable distance round the plate marked A, and at 795 pounds the increase on the original diameter of the barrel was at the parts marked B, C and D $\frac{5}{8}$ of an inch, whilst at the bands it was only $\frac{1}{16}$ inch. A hole in the top plate, into which was screwed the connection to the pressure gauge, was stretched about $\frac{1}{16}$ inch oval, and the leakage at this hole, at the crack and at the joints, was so great as to completely overpower the pumps. Table C gives the detailed results of this experiment, which seem to indicate that, in consequence of the great stretch of the material the leakage at the joints in steel boilers, even although double butt-strapped, would give warning of the excess of pressure long before the bursting point was reached.

At present it is scarcely practicable to rivet together with ordinary appliances plates of a greater thickness than say $1\frac{1}{4}$ inches, but it seems not improbable that we may before long be able to dispense entirely with longitudinal riveting, and thus minimise the difficulty now experienced in working heavy plates. The idea has now been revived of rolling boiler shells in broad solid rings, and I am assured by several of the steel makers in this country that it is quite practicable to produce by this method cylinders of from 9 to 11 feet in diameter. A step has already been taken in this direction by an eminent steel manufacturer, who is now rolling solid cylinders of large diameter, which, when attached together, it is intended to work with compressed air at a pressure of 1,000 pounds per square inch. Fig. 3 is a vessel constructed in this manner, and Fig. 4 illustrates the same principle proposed to be carried out in the case of an ordinary marine boiler.

Table C.—Test of Experimental Steel Boiler.

Description of Boiler.

Length inside 10 ft. 6 in., diameter inside 4 ft. 4 in.
Plates $\frac{1}{2}$ in. thick, bands 5 in. wide, $\frac{9}{16}$ in. thick, two rows of $\frac{3}{4}$ in. rivets.
Thirty-seven longitudinal stays (steel) $1\frac{1}{2}$ in. diameter with $1\frac{3}{4}$ in. ends, and nuts.
Angle iron at flat ends, Low Moor iron, 3 in. by 3 in. by $\frac{1}{2}$ in. full, $\frac{3}{4}$ in. thick.
Flat end plates (steel) $\frac{1}{2}$ in. thick.

Order of Test.	Pressure per Square Inch in Pounds.	Increase in Circumference at Bands in Inches.	Increase in Diameter.	Bulging of End Plates (flat).	Bulging of End Plates (flanged).	Result.	Remarks.
1st	252	nil	nil	nil	nil	Tight	
,,	336	$\frac{1}{32}$	not perceptible	do.	do.	One longitudinal stay leaking, 3 rows from bottom One ditto ditto at top	Stopped test and took off nuts of stays to caulk.
2nd	336	$\frac{1}{64}$	ditto	do.	nil	Tight	
,,	448	$\frac{1}{16}$	ditto	$\frac{1}{8}$	do.	Ditto	
,,	560	$\frac{1}{16}$	ditto	$\frac{1}{8}$	do.	Leak at brass plug	
,,	616	$\frac{1}{16}$	ditto	$\frac{1}{8}$	do.	Heavy leak at brass plug, rivets in band, and angle iron ring	Stopped test, caulked band nearest flat end of boiler and tightened brass plug.
3rd	616	not gauged		not gauged		Tight	
4th	616	$\frac{1}{16}$	not gauged	$\frac{1}{8}$	nil		
,,	694	...	ditto	$\frac{1}{8}$	do.		
,,	728	$\frac{1}{8}$ full	ditto	$\frac{3}{16}$	do.	Band split transversely 1 in. between rivets, brass plug leaked badly owing to hole in plate, elongating flat plate cracked—for 2 ft. 6 in. length between rivet holes	Permanent set at flat end $\frac{1}{16}$ in.
5th	336	...	...	$\frac{3}{16}$	nil	Slight leak at crack rivets ditto, flat end	
,,	588						
,,	700	not gauged		not gauged		Sharp crack—flat plate broken between rivets, leaking badly	
,,	784						
,,	795	$\frac{1}{8}$	$\frac{5}{8}$	$\frac{5}{16}$	...	Crack in flat plate leaking badly, rivets leaking, hole in plate with brass plug for pressure gauge drawn oval and leaking badly, so much so as to render it impossible to increase the pressure	

FIG. 3.

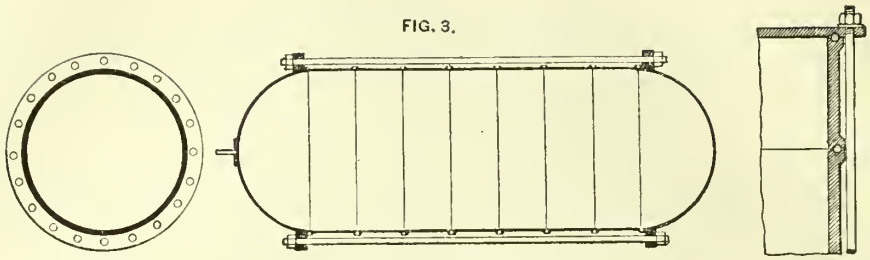
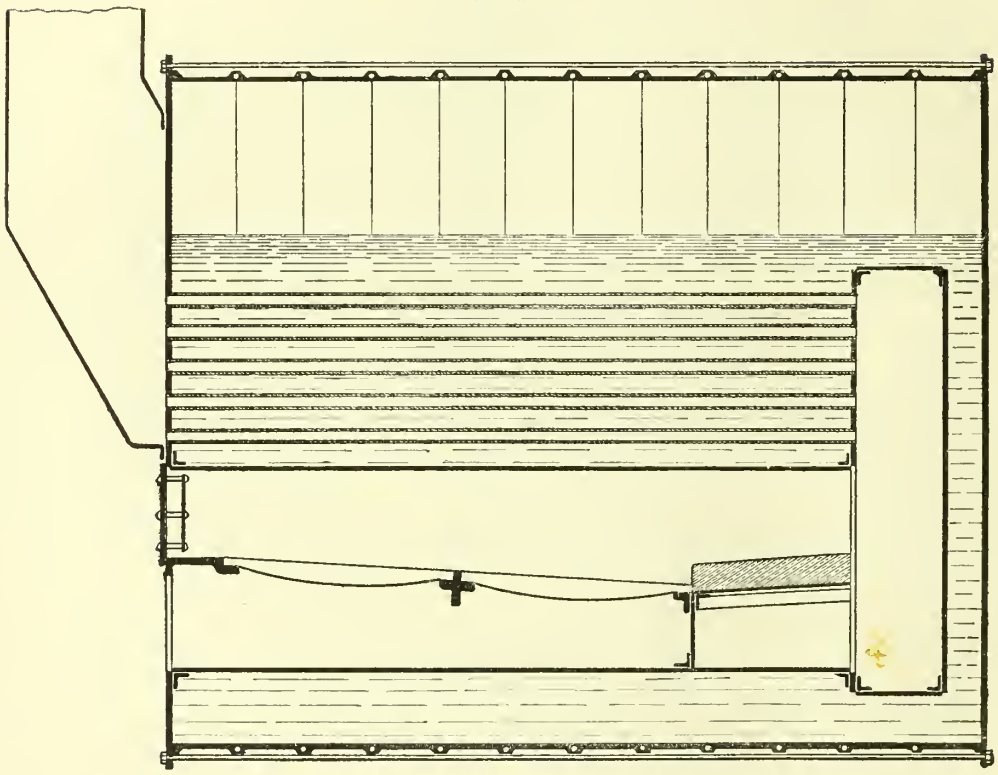
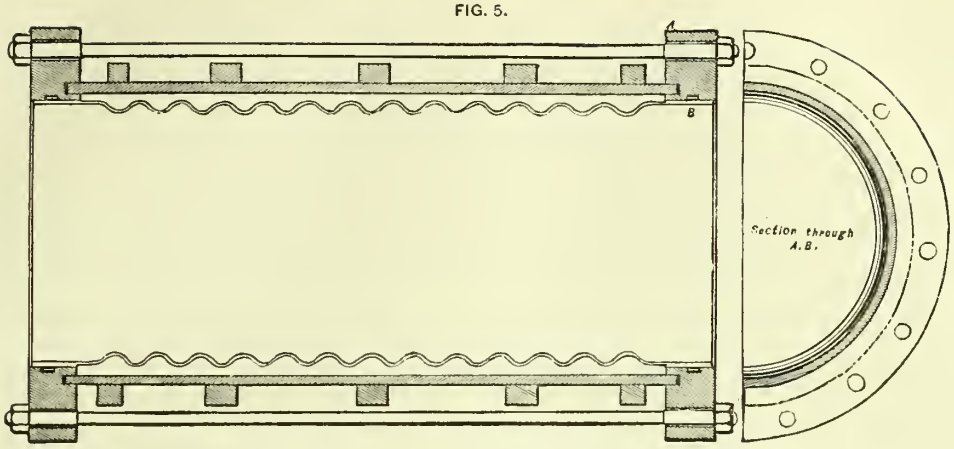


FIG. 4.



But while we are thus increasing the strength of shells the one weak point in the boiler is the furnace; for although steel furnaces will undoubtedly be stronger than iron ones of the same dimensions, yet the transmission of heat demands that the thickness of the furnace-shell shall not be materially increased, and the stiffening rings necessitating riveting, &c., which are found in high-pressure boilers invariably occasion trouble at sea. It is therefore gratifying to mention a recent improvement which bids fair to fulfil all the requirements of the case, by supplying the necessary strength without increasing the thickness of the plates or having recourse to objectionable strengthening rings. This consists of a corrugated form of flue patented by Mr. Sampson Fox, of the Leeds Forge Company, to whose courtesy I am indebted for Fig. 5 showing this flue, together with the apparatus employed for testing it. The strength of this description of flue

FIG. 5.



seems to be that due to the direct crushing strength of the material, and the experiments recently conducted to ascertain its collapsing strength, in comparison with the ordinary plain flue, showed that the corrugated iron furnace had at least twice as much strength as the plain one; so that the working pressure could with safety be doubled so far as the furnace is concerned. Of course, if this form of furnace were rolled in steel the increased stiffness of the material would produce a corresponding increase of strength. From the peculiar form of the flue it also possesses a more extensive and therefore more efficient heating surface than that provided by the plain furnace.

Now as we have a material that gives us a boiler about 30 per cent. stronger than an iron boiler of the same scantlings, and as it seems possible that we may be able in the immediate future to dispense entirely with longitudinal riveted seams by having the shells rolled, and as there has also been a furnace introduced which can be worked at twice the pressure of the ordinary plain flue, it does appear to me that we have succeeded in a great measure in removing the old conditions that have militated against much higher pressures being obtained, and that we appear to be now in a position to make a fresh departure in the direction of still greater pressures. If the improvements which I have indicated prove, as I have little doubt they will prove, successful, we shall have gained an advantage represented in the aggregate by an increase of about 80 or 90 per cent. of the working pressure. In other words we shall be able to work the present form of boiler at 160 or 170 pounds per square inch; and, although the resultant economy will not be so great as that which attended the increase at one step from 30 to 60 pounds, we may confidently anticipate that it will be sufficient to give a great impetus to steam navigation, advancement in which has lately been so much retarded by the high consumption of fuel.

DISCUSSION.

The Chairman (Mr. J. Scott Russell, F.R.S., Vice-President): I am sure that we must have all heard this Paper with very great pleasure. In the first place, the information which it gives us is exactly the information we want; and, in the second place, it is conveyed to us by a most competent gentleman, and conveyed to us as the result of very serious experiment. For my part I am very anxious that steel should be introduced, because of the great advantages we should derive from it. I am very anxious for the same reason that steel should not be prematurely introduced, or in any doubtful or ambiguous manner, and to show us how to avoid that evil is one of the great values of this Paper. I am very glad that Mr. Parker has touched on one point, which I will call your particular attention to, namely, the point of the internal furnace or tube, because I need not say to you one of the great defects of steel would be this, that while a much thinner plate would stand the external force, a thin plate would be more liable to crumble from the external force, and that would be an evil which in its simple form could not be got over. I consider it a valuable point in this Paper, to which I beg your attention in the discussion of it, that this almost unavoidable evil is most elegantly got over by an invention, which really is the carrying out, in a much more refined form, of an old invention of our friend Professor Fairbairn, who invented the putting a ring all round, so as to give it depth without too much thickness. I hope you will give a thorough discussion to this Paper, because I think we are at a critical moment with regard to the introduction of steel for boilers; and I think also, at this moment, it is of very great consequence to steam navigation thoroughly to study how you are to get the highest pressure with the greatest safety and the greatest efficiency. There are many gentlemen here who have given the subject of boilers and steel their careful study, who I am sure will be able to speak upon this subject, and we shall be all grateful for any additions to this most valuable Paper.

Mr. A. C. Kirk (Member): Mr. Chairman and Gentlemen, as I had the honour to read a Paper at the Glasgow Meeting on riveting and steel plates, and as I have had some little experience in their use, will you permit me to make a few remarks on Mr. Parker's Paper? I think Mr. Parker in this Paper has done us very excellent service. He has brought together the experience up to this time in the use of steel, and being a new subject it is of great importance to us all that that experience should be brought up to date. There has been immense progress made in the manufacture of steel, and I am also happy to say there has been great progress made in the method of treating it by those who use it. There need now be no fear as to the manufacture of wholesome steel for the purpose of riveting or plating. Steel may be punched or drilled, but if it is punched it must be subjected to treatment which, though beneficial in the case of iron plates, is I think I may say absolutely essential in the case of steel plates. As to the cause or theory of the great diminution of strength when steel plates are punched compared with iron ones, it is perhaps premature to say much, still I think it may be said to be entirely due to the punch producing a ring of extremely compressed material round the rivet hole, which expanding in diameter under the pressure of the punch acts like a wedge, and brings the whole section of the plate into an extreme state of tension. I think that is proved by the fact that where you drill out a thickness of about $\frac{1}{8}$th inch, which seems to be the extent to which this metal extends, then the plate is relieved from the bursting stress which is put on its rivet space, and the rest of the metal yields pretty nearly its full strength. In iron that does not happen to the same extent, which is mainly due to the looser texture of iron. Wrought iron is a looser sort of material. When put together by the process of welding it is intimately mixed with little particles of cinder, and it does not seem as if strains were propagated through steel in the same way as they are propagated through the looser material that iron is. I do not know that I make myself quite clear in the matter, but I will endeavour to describe to the Institution the experiments which I made six months ago. Take the holes in the plate, for instance, which we tested. Unless we had a much larger section of plate from the pin-hole to the end than you require in an iron plate, the steel plate split under the pressure. You could in them see quite well inside the hole that the pin of the testing machine had compressed the metal, thickened it up, and as it were inserted a wedge in the plate. When fracture occurred in this way, the fracture propagated through the plate was invariably crystalline, although the same plate when broken asunder in the testing machine exhibited a

silky fracture. I am not prepared with any theory to explain that. But the same thing showed itself when the punched holes were torn asunder, and when the compressed metal inside the rivet hole had not been previously removed; the silky fracture was lost very much, and a sort of crystalline fracture set up. There is one other point—the corrosion of steel plates—and there I quite agree with Mr. Parker, that we must depend more upon the result of actual experience than upon laboratory experiments made with definite chemicals, because as to boilers I think chemists do not know much more than we do what are the special corrosive agents, and it is rather uncertain work to reduce it from the steel used some years ago, because most of it was puddled steel, in which (and Dr. Siemens will correct me if I am wrong) no manganese was used; and if an excess of manganese is the cause of abnormal corrosion, it is quite possible the results drawn from experiments with puddled steel might not be fairly applicable to the steel of this day. One thing I noticed in the building yard in working steel was this, that while most of the steel welded quite freely, if the smith lost his first heat and tried a second heat, it was extremely difficult to get it to weld. I asked some chemical friends of mine what they thought could be the cause of this, and the suggestion made (as to which I am quite open to correction, as it is strictly theory) was, that there might be oxide of manganese formed from the excess of manganese in the steel. However, there is no doubt that as the quality of steel is improved it is approximated more and more closely to pure iron. I feel quite confident of that. Yesterday I recounted to the Meeting some experiments of welding together slabs composed of cuttings partly of steel and entirely of steel. All of these welded perfectly. I do not know what the per-centage of manganese was in them, but they were remarkably good plates, and probably it was low. The best steel at the present day may be considered as very pure and perfect iron, differing chiefly from iron in its mechanical texture in being perfectly close and homogeneous, and having no open spaces or foreign bodies intermixed with it. I am very glad also that Mr. Parker has brought before the notice of this Institution this arrangement of corrugated flues. Of course there is no doubt that the flues of marine boilers have been, at very high pressures, the most unmanageable part of the arrangement. We have adopted different kinds of stiffening rings, some of which have done very well on the whole—that is to say, rings detached from the furnace and attached only to the furnace by a succession of studs exactly like the bridges across the top of a locomotive firebox—these extended around and did not interfere with the access of the water to the furnace plate, and certainly gave a great support. But there is no doubt that this corrugated flue is an improvement, and a very elegant improvement. I do not really attach so much importance to the increase of heating surface—I think that has been made too much of—but the flue is such a good one that it does not require these adventitious excellencies to be made so much of as they have been. The fact is the flue is a strong flue and a light flue, so strong that it will enable higher pressures to be carried. Mr. Parker further told us that he had made a number of experiments upon the staying of flat surfaces. That is such an important point that I hope at another Meeting Mr. Parker or somebody else will be able to lay before us a complete set of experiments bearing upon it. I do not know whether Mr. Parker's experiments have gone so far as to enable him to do so yet; I suppose they have not, or he would have given us the benefit of his experience. That is a point on which perhaps we know less than upon any matter in connection with the staying of boilers—about the deflection of the squares between stays in flat plates. The point of interest is not so much to my mind the ultimate bursting strength of the surfaces, as the pressure at which deflection commences, because with screwed stays fixed through the plate as soon as deflection commences the attachment is nearly gone. The plate bends, very much like an india-rubber valve when you pull it by the centre, and opens off the screw. If it is riveted the small rivet will probably give way, and the plate is blown off the rivet head at a pressure much below what it should be. If there is a nut behind to support it, it will not probably be blown off at such a low pressure, but the result is not much better, because the plate opens from the screw, the salt water gets access to it, and the thread is speedily destroyed, and leakage commences to such an extent that in a short time danger will result.

The CHAIRMAN: Do not you generally use both an internal nut and an external one, and also a washer of metal under each; and does not that make a perfect end to the stay?

Mr. A. C. KIRK: I am very glad that you brought up that, because perhaps it may tend to make the matter more clear. In the case of staying the end of the boiler, as we see here, we should most probably do as you have said, and it would be very good practice to do it. I was rather speaking of staying the flat sides of furnaces. Then there is another objection to putting nuts on stays, that if the

temperature is very high, or if very flaming coal is used, these nuts almost always get overheated, and they then expand and ultimately get slack; and the only arrangement, as the experience of locomotive engineers has pretty well settled, is to screw a stay through and rivet it, but such a surface is practically done for when deflection of any sensible amount takes place. We are indebted to the gentlemen who have introduced the materials to us, and also to our friends at Lloyd's, who have completely broken through the traditional and artificial rules and proportions that some of our other friends in power have saddled us with—excessive proportions, excessive weights, and many other things that we need not here enter into, but which at all events amount to a very serious incumbrance not only on the manufacture of engines, but on the remunerative and paying power of ships after the engines have been manufactured. I hope that the influence of this Institution will in due course of time be brought to bear further upon this subject, so that we may have relief from some of these oppressive regulations, and follow more in the wake of what this very responsible body of Lloyd's has pointed out. I hope that I have not occupied too much of your valuable time.

Mr. JAMES WRIGHT (Vice-President): There is just one point in Mr. Parker's very excellent Paper which leaves a little doubt in my mind. I quite agree with him in his opinion as regards the excellent quality of steel now to be obtained, and as to the facility with which it can be worked up into boilers. All that can be done now without fear of bad consequences. I think he said he had agreed to a reduction of of thickness of 25 per cent. That is the difficulty I have. All of you are aware—and no doubt there are many Members here who are connected with the Navy—that we have suffered very much from the corrosion of boilers; and the corrosion of steel is, I think, still an obscure subject. So far as our experience in the Navy goes it has not been fortunate. A number of years ago a quantity of steel boilers were made, not of such steel as we can obtain at the present day, but considerably stronger and harder. I believe the breaking strain was from 35 to 36 tons, and so brittle was it in some cases that it split across in punching. Still it did not resist corrosion at all well when used with salt water in the boilers. One case was very bad; it was a low-pressure box boiler working at 16 pounds to the inch, and wore out in about $2\frac{3}{4}$ years. I should say that that boiler was made only $\frac{1}{4}$ inch thick instead of $\frac{3}{8}$ths, which it would have been made if iron had been used. Take a $\frac{1}{2}$-inch plate, and then take 25 per cent. of thickness off that.

Mr. WILLIAM PARKER (Member): The reduction of 25 per cent. is for cylindrical shells and stays only—not for flat plates.

Mr. J. WRIGHT: That makes a difference; but still if the iron and steel shells are only of equal strength at first, and the rate of corrosion is equal, the steel shell will lose strength more rapidly than the iron one. I was going to say this also, that the Boiler Committee have been making a great many experiments on the subject of corrosion of steel, and the general conclusion which they come to was that it was rather more rapid than the corrosion of iron. The doubt in my mind is whether it would be wise to reduce to such an extent as Mr. Parker mentions the thickness of the plates. A short time ago the Admiralty ordered some steel boilers for the *Iris* of the same quality of steel as the hull was made of. A beautiful material it was, but on account of the question of corrosion it was not thought desirable to reduce the thickness much. It would have been $\frac{3}{4}$-inch thick if it had been made of iron, and it was only reduced to $\frac{11}{16}$ths. That was simply from the fear that the corrosion might be more active than, or at least as active as, in iron.

Mr. W. PARKER: Shell plates?

Mr. J. WRIGHT: Cylindrical shell plates. On the other hand we have had for many years in the Navy a great many small boilers in steam boats and pinnaces, and I think they have lasted very well. They were made a $\frac{1}{4}$ inch to begin with, and $\frac{5}{16}$ths, and generally lasted about a commission. In that case they are generally used with fresh water or water nearly fresh. There is one other subject I should like to mention, and that is with regard to this corrugated flue. I understood that Mr. Parker was present at the experiments which were made, and I will leave him to tell us how much the flue extended lengthways under pressure. Boiler flues, as used generally, serve as stays to the boiler, and I fancy that a corrugated flue might have a certain amount of elasticity which would deprive it of some of its use as a stay. On the other hand the plain flue was, I believe, free at the ends, and that it collapsed under a pressure of 200 pounds. I think if it had been fixed at the ends it would have stood a greater pressure; but I think that the experiment did not give fair play to the plain flue, because if it did, we have been working with plain flues with rather too small a margin of safety.

The CHAIRMAN: I would merely call Mr. Wright's attention to the interesting fact, which he is acquainted with no doubt, that in the inside of boilers it often happens that a thin plate lasts longer than a thick one, the reason being that owing to the non-conduction in a certain degree of heat through the plate, the inside of a thick plate becomes more overheated than the corresponding side of a thin plate. That is on the other side, and may in some degree counterbalance the argument.

Mr. JOHN R. RAVENHILL (Member of Council): The Paper we heard yesterday read by Mr. Martell, followed as it has been to-night by this Paper of Mr. Parker's, must satisfy everybody that the time has arrived when steel is to be used most extensively if not entirely both in the hulls and in the boilers of our commercial marine, and doubtless also in vessels for the Royal Navy. Those gentlemen have given the Institution the results of very elaborate and valuable experiments, and we ought to appreciate the kindness of Lloyd's in giving us those results, and not only us but also the world at large. There was a time, and it is not so very far distant, when Lloyd's Register of Shipping was looked upon as old-fashioned. It was thought to be useless to go to them; but Mr. Parker certainly has eclipsed anything that has been done to my knowledge, because he has given us the results of information received up to the morning of the reading of his Paper. He has certainly broken the rule of keeping the Paper till the last moment, but I daresay the Council, under the circumstances, will be willing to condone the offence. He has alluded to experiments that he is making, I believe at the present time, if I gather rightly what has fallen from him, on flat surfaces, and he proposes to continue them. I take it that there are few things that would be more valuable or more interesting than a collection of experiments on stayed flat surfaces — not on the plates as in water tanks, but with the plates subject to various temperatures, representing, in point of fact, the flat surfaces of the combustion chambers in high-pressure boilers. The Americans, some years ago, did conduct a series of experiments, I believe, and they were published; but nothing much has been done in England since that date to my knowledge; and now that Lloyd's Register of Shipping have come to the fore and have gone thus far, I hope they will go still further and carefully carry out those experiments and have them accurately recorded. We want a great deal of information on this particular subject, and nobody knows better than Mr. Parker himself that the want I allude to is in every sense a real want. While he is conducting those experiments he will doubtless also learn how best he may fit the stays in plates so as to prove a point upon which there is a difference of opinion, and to which some allusion has been made. It will then be seen whether the best results will be obtained by stays being tapped into the plates with a simple nut or with a washer and a nut, or riveted heads, or in any other form which he may like to try during those experiments. He has brought, as I said before, those experiments up to the present time, and knowing myself how carefully they have been conducted in his hands, I feel there is nothing we can say on the information he has placed before us to-night except, perhaps, to ask him a few questions. There is a question about that corrugated flue which I should like him to give us his experience on. Some time back I was talking to him about that form of flue, and expressed a doubt as to whether difficulties might not arise unless the perfect form throughout could be maintained; and it occurred to me that practically some difficulties would be experienced in maintaining that circular form just at the outset of their use, and it was a matter which I thought ought to be seriously looked to. I have no doubt he has done so, and can give us some information upon it, although he did not allude to it in his Paper. Mr. Wright made some remarks as to the elongation of that form of plate, and I quite agree with every word Mr. Wright uttered. There is one point I should like to allude to in connection with steel boilers, and it is this—that there is such a vast difference in the management of boilers, in the every-day working of the boilers between the vessels in our commercial marine and in vessels of the Royal Navy, that I think Mr. Wright is prudent in adhering to a greater thickness of plate than other gentlemen are inclined to use in the commercial marine. As we all know, Her Majesty's vessels leave England for long terms—perhaps for three years—and we know very well that if anything does go wrong with a vessel of the Royal Navy, there are plenty of kind friends to publish it. With the commercial marine it is different, and a vast deal goes on there that nobody knows anything about, unless it is just those who are connected with the ease and a few surveyors who may be fortunate enough to hear of it, and able to obtain the experience it gives them. I think if Mr. Parker can supplement his Paper in the way I have stated he will increase its value—a value which we must all admit is very great.

Mr. BOYD: As a visitor here this evening, I have some reluctance, Mr. Chairman, in intruding myself upon the Meeting, but I think I am in a position—as the author of the Paper that has been read

at a neighbouring Institution this morning—to make two or three remarks on the subject which has been alluded to by the two previous speakers, namely, the staying of flat surfaces. I may say, in explanation, that these experiments were conducted under the supervision of Mr. Parker and Lloyd's Registry, and they were conducted on the first boiler which was submitted for their approval. The experiment that was made was a very simple one, but the results shown are rather interesting. Two boxes were constructed representing as nearly as possible a piece of the combustion chamber of a marine boiler. I will take for illustration the end of the combustion chamber in Fig. 4 of Mr. Parker's Paper. These boxes were about 3 feet square, and they each of them contained nine stays. I may say that the original object of the experiment was to exhibit the different degrees of buckling in iron plates of $\frac{1}{2}$-inch thick and steel plates of $\frac{7}{16}$ths. That was the original idea with which the experiment was undertaken. The experiment was conducted with the stays riveted over in the usual way—that is to say, without nuts and without washers, or supports of any kind, the stays being simply screwed into the plates and riveted over in the usual way. It is a matter of interest, but the question at issue, as I understand, is not so much the relative buckling of iron and steel as the relative buckling with different kinds of support.

Mr. J. R. Ravenhill: At different temperatures of the plate?

Mr. Boyd: Of course the different temperatures of the plates add an additional interest to the experiment. I am quite willing to admit that, but it is open also to the difficulty of carrying out the experiment. The difficulty of conducting an experiment and measuring accurately the amount of buckling of a steel or iron plate while that iron plate is subject to the intense heat of a furnace is naturally a difficulty that will, I think, occur to the minds of most here. I regret to say that that difference of temperature is not one which we were able to accomplish; but at a normal temperature the experiment was performed. The plates, as I say, were riveted over in the ordinary way, without nuts and without any additional support on the heads. Without going into details or wearying the Meeting, I may say the buckling took place at 130 pounds in steel plates, and the box ultimately burst at 550 pounds. I will not trouble the Meeting with the result as to ordinary plates. The box I mentioned burst at the lip of the riveted stay, that is to say, the head of the rivet flew off, and we were unable to continue the pressure any longer. Having these boxes made, it occurred to us that it would be a matter of interest to try another set of boxes with nuts on the heads on the outside, only not on the inside, as is represented on the back of the boiler in the drawing. The buckling commenced in that case not at 130 pounds, but at 260 pounds, that is to say, the plate was stiffened by the nuts and washers to the extent of 100 per cent.

The Chairman: Were there washers on the nuts?

Mr. Boyd: Yes, the diameter of the washers was the same as the points of the nut.

Mr. Ravenhill: What was the extreme diameter of the rivet head?

The Chairman: Do you remember the thickness of the plate and the diameter of the bolts?

Mr. Boyd: I can tell you those exactly. The thickness of the steel plate was $\frac{7}{16}$ths; the diameter of the stay bolt was $1\frac{3}{8}$ inches; and then the diameter of the head when riveted over would be about $1\frac{7}{8}$ inches.

Mr. Wright: Would you propose an arrangement of nuts and washers for the inside of furnaces?

Mr. Boyd: I will give you the result of the experiments first. The plates, as I say, were fitted with washers. The buckling showed at 260 pounds, and the bursting strain rose from 550 pounds to 950 pounds, and the fact is that the plates never cracked at all. Before the plates could be cracked, the structure of which the box was made gave way; but in the case of the steel and iron plates the flat stays on which we were experimenting remained uncracked and uninjured in any way, but at 1,000 pounds the strain was so great that the box to which these flat plates were connected gave way, and the experiment was at an end.

The Chairman: What was the distance of the centres of the plates from each end?

Mr. Boyd: Nine inches. With reference to the question of fitting nuts inside the combustion chamber, I know that that is a difficulty. Probably every gentleman present is well aware, much better than I am, that there are many boilers so fitted; and provided the nuts are not too thick, and provided the boilers are kept clean, and the nuts properly looked after, I think there is no particular danger; and no doubt, as is shown by these experiments, to which I have already referred, you get an immense increase of strength; but if the nut is allowed, or in fact if the boiler generally is allowed to become neglected, and a large amount of deposit is allowed to take place in the narrow space at the back of the nut, and

the boiler is not kept clean, no doubt the plate is very apt to burn away, and you rely upon something which is unreliable; but it is a thing which is, I will not say, common in practice, but which exists in practice, that these flat surfaces should be fitted with these nuts, and I think that the immense amount of additional strength given to the flat surfaces by the fitting of these nuts certainly warrants us in taking into consideration whether they might not be advantageously used. I should like to ask Mr. Parker one question, and it bears upon this same point. In regard to Fox's furnace it has always appeared to me to have this element of danger in it. On the upper side of the furnace those corrugations would become the receptacles for deposit which would be liable to injure the plate, and then the flame striking the underside of the curve on the reverse side of which would lie this deposit, the plate would be very apt to burn away and to crack where the deposit was made. I should be glad to hear Mr. Parker's opinion upon that.

The CHAIRMAN: Is there not another point of view—that there might be rather more current downwards in that very groove, and so carry the deposit to the other side?

Mr. J. FORTESCUE FLANNERY (Member): Mr. Chairman and Gentlemen. This Paper is a very interesting one, not only on account of the subject, but I think for a stronger reason. It shows what are Mr. Parker's views, and we all know that Mr. Parker, by reason of his official position, can do a great deal either to assist or delay any improvement in the mercantile marine; and it is very satisfactory to find he is not one whit behind Mr. Martell in his eagerness for progress, and indeed in his Paper he has perhaps shown a tendency to go a little further forward than some other engineers who follow him. One remark fell from Mr. Kirk that I think hardly had the importance attached to it by the Meeting which it deserved, and that is that the metal we are now using has very little claim to the title of steel, but is almost entirely pure iron. So lately as the latter end of 1875, it became my duty to report upon the desirability of fitting steamers with steam boilers. I had not the opportunities Mr. Parker and others have had of knowing what was being done throughout the country at the time, but I became acquainted with all the methods of manufacture, and the results obtained by the Bolton Iron and Steel Company. I also knew pretty thoroughly what was being done by Mr. Webb, at Crewe; and having this information I consulted with the manager of one of the first firms upon the Thames—one of the most experienced engineers in London—and we came to the conclusion that with the materials then in use it was not at all desirable to report in favour of the use of steel for boilers. That firm had already made one set of boilers of steel with very contradictory and irregular results. That was so lately as the latter end of 1875, and I mention that circumstance because I wish to give more point, if possible, to Mr. Kirk's remark that the material we are now using has no claim at all practically to the name of steel. That being so, we must entirely cut ourselves off from the experience that we have had with steel in boilers, because the material we are now using is so entirely different, that the experience we have had is no criterion as to what the results may be which you may get from the material as at present supplied. I had the privilege of hearing a Paper which was read by the last speaker at the Institution of Mechanical Engineers this morning, and I think he might, with great propriety and great advantage to the Meeting, have dwelt even more upon the facts he gave in that very able Paper. I studied it carefully, and it seems to me that four very important conclusions were arrived at by Mr. Boyd, not merely from his experiments but from his experience in manufacturing boilers—the very first pair of boilers of steel that went to sea. The conclusions he arrives at are that with the present system and facilities for manufacture we can obtain plates of almost perfect uniformity with the restrictions as to test which are being insisted upon by Lloyd's. There is no injury to these plates by drilling, and the only injury that is produced by punching can be perfectly annihilated by subsequent annealing; and the only point to which very special attention in staying should be given in making boilers is the staying of the flat surfaces. It is evident from the results which Mr. Boyd has obtained that we have now at last found ourselves in a position to make marine steel boilers. The only question remaining to be proved, and nothing but time can prove that, is how long they will last—whether they will be more or less liable to decay than boilers made of common iron?

Mr. MICHAEL SCOTT (Member): I have had some specimens of steel sent from Sheffield by Mr. Thomas Hampton from the Phœnix Steel Works, which may interest some Members more particularly with regard to the question of welding. The process is intended for armour plates, but would be applicable for plates for other purposes. Ingots are to be cast in the ordinary way. They are then hammered into slabs and rolled into thin sheets, and in the specimen shown as many as one hundred

and twelve sheets were welded at one operation. This would be done in an armour-plate furnace by passing them through the armour-plate rollers. In this specimen you can see the laminæ quite distinctly. He proposes then to hammer the surface of the armour-plate which is represented by this end of the specimen. Off that end a portion has been cut, and that has been subsequently punched cold in the direction of the reed of the laminæ without the slightest appearance of injury to the metal. I understand that he also proposes to employ it for boiler plates as well as armour plates; and he adds that the cost of the operation would leave the armour plate at about the same expence as the iron, the great difference being the diminished waste in the steel during the manipulation as compared with the iron.

The following communication from Mr. Hampton was handed in by Mr. Michael Scott:—

"Phœnix Bessemer Steel Works,
"The Ickles,
"Sheffield, April 3rd, 1878.

"Hampton's Patent Toughened Steel Armour Plates.

"The steel may be manufactured either by the Bessemer or Siemen's process (the former preferred), "and the raw materials are selected from the best brands of Swedish and English Hematite pig irons, "together with ferro manganese or spiegeleisen.

"The steel contains only a very minute proportion of carbon, and is comparatively free from "phosphorus.

"The ingots are cast in ordinary moulds, and after being hammered, or cogged by rolling into slabs, "are then rolled into thin sheets or plates for the purpose of imparting toughness and tenacity to the "metal. The sheets or plates so prepared are afterwards piled in the armour-plate furnace for the purpose "of heating and welding—'the latter process being effected by passing the pile through the armour-plate "mill rolls. Precisely in the same manner as ordinary wrought-iron armour plates are produced.'

"The usual difficulty in welding steel is obviated by reducing the slabs into *very thin layers* as "previously described, and, with ordinary care, will stand as much fire or heating (without in the least "deteriorating the quality of the steel) as wrought iron.

"After the armour plate is rolled to within about 2 or 3 inches of the thickness required, it is then "hammered to finished dimensions by means of a steam hammer, 'the latter process being intended to "give additional density to the surface of the steel, and thereby render the resistance to penetration more "effective.'

"The cost of manufacturing steel armour plates by my method does not exceed the present cost of "making wrought-iron plates of any thickness for ship's armour or coast defences.

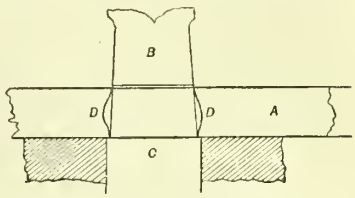
"(*Signed*) THOS. HAMPTON."

Dr. Siemens (Associate): I think this Paper of Mr. Parker's has brought before us some very important matter, and the questions arising upon it have been so well discussed already that I feel it is almost unnecessary for me to say anything.

The Chairman: There is a question upon which you can give us some important information, namely, whether the thing called steel and the thing called iron exist any more as separate existences?

Dr. Siemens: Chemically speaking the only difference is that what we call mild steel is pure iron—it is more essentially iron than what is commonly sold as such; but as regards the physical properties of the material, it differs in many points from iron and ought not to be confounded with it, because if we were to call it iron and confound it with iron, we should think it right to treat it in the same manner, whereas it requires in many respects different treatment. In fact, Mr. Parker has given you one or two instances. I had occasion to allude at another place to one point which was brought before my notice very forcibly with regard to the steel boilers which Mr. Boyd has constructed. After testing samples of the plates that were supplied by the manufacturers the rumour was spread that the material was wholly unreliable—that instead of breaking through the riveted seam, through a narrow strip of metal, it broke through a line of 50 per cent. greater extension rather than through the narrow place; and as iron would not have given way in that manner, and as the experience of engineers has been derived from iron, it was at first concluded that the new material was not reliable; but it was soon discovered upon further investigation that the method of riveting employed had been such as to be unsafe for this mild steel. Two large rivets had been put in a forward position and other rivets to make up the holding strength between the piece under test, and the shackles yielding were put back. In dealing with a material like this mild steel, the strain

comes entirely upon the forward rivets, whereas the backward rivets being, as it were, the elongation of a much larger piece of metal, do not feel the strain at all. As it appears to me these two forward rivets were near the edge of the metal and they set up a tearing action. Now it was remarked that although the sample was expected to elongate 25 per cent. before rupture took place, it did not elongate at all, but broke in the manner already alluded to. In further testing this metal it was found to be perfectly homogeneous and capable of an amount of elongation of 25 or 28 per cent. before breaking. If you take a strip of india-rubber you may elongate it to several times its length, but if you make the least nick in the edge of the india-rubber and try to elongate it, it will tear readily. In the same way if you give this mild steel a chance of tearing it will tear. In that case no elongation will take place, because in tearing the strain is confined to an infinitesimal amount of area, and its course in fracture will be the result not of the total amount of resisting area, but of the direction the tearing action may chance to take. With regard to riveting Mr. Parker states, and perfectly correctly I need hardly say, that in punching a plate such as is used in the construction of large boilers, the metal in the act of punching is reduced 30 per cent. in strength. Mr. Kirk has already offered an explanation which is similar to the explanation I should give; but with your permission I will draw attention, perhaps a little more, to the precise action that I conceive takes place in punching a thick plate of this material. If you will allow me I will make a little sketch. Suppose A to be the plate to be punched, B the punch, and C the supporting die. As the punch penetrates into the metal, the latter does not immediately sever: it will first yield by compression, and it will as it were be forced laterally into the mass of metal surrounding the punch, where it will create the zone of highly compressed metal represented by the lines D D in the sketch: the metal beyond this zone of compression will be to a certain extent under tension. If the piece punched out is afterwards examined it will be found to be about 10 per cent. thinner than the original thickness of the plate, and that diminution in thickness is accounted for by these forces of compression and extension set up within the metal. If the plate is now subjected to a tearing strain, it has to resist besides this, the abnormal states of strain into which it has been thrown by the punching action, and is therefore destroyed with a force considerably less than that it can resist in its original condition as the Paper shows. Now if this plate after the punching has taken place is subjected to annealing, then this strain between metal and metal will be relieved and the plate will regain its full strength; or, if this strained metal D D be rimed away and the hole be enlarged the plate will have its full strength. But I have the results of some experiments which were made by Mr. Riley at the Landore Works, near Swansea, proving that punching does not weaken the plate but increases the strength of it. His experiments were not confined to one or two cases, but comprised a whole series that, strange as it may appear, went to prove that the punching absolutely increased the tearing strain of the punched plates, without annealing, to something beyond the strength of the plate per square inch before it was punched. I should first say he used the precaution of making the die below the punch larger, to perhaps a greater extent than is usually done, and the result was, to my mind, that the mass of metal under compression of which I have spoken was not formed—and that the plate was thus relieved from the abnormal strains generally produced in punching. Under these circumstances I can understand that a slight increase of strength should take place for the same reason that if you subject a bar of metal of any form to strain its strength will be increased. It is a subject perhaps not sufficiently understood, but I have had an opportunity of observing very extraordinary results in that way. Take a bar of iron or steel and subject it to a strain exceeding the elastic limit, and allow this strain to be active for some time, in testing the same bar again you will find not only the elastic limit has been raised, but that the ultimate breaking strain is considerably increased. In that way whatever strain you put upon a piece of metal you increase its strength, unless the strain is applied in such a way as to set up contending forces within the metal. Mr. Parker has alluded to two forms of construction with regard to marine boilers. The one is the admirable furnace of corrugated form which is represented by the drawings, and which I quite believe is a step in the right direction. The other is an experiment of construction which I had occasion to make, and which, by Mr. Parker's request, I have put before the Meeting in Drawing, Fig. 3. I was asked to design a vessel that could resist the pressure of at least a 1,000 pounds per square inch, and with a capacity of not less than 100 cubic feet. The mode in which such high-pressure air vessels have been hitherto constructed has been in making

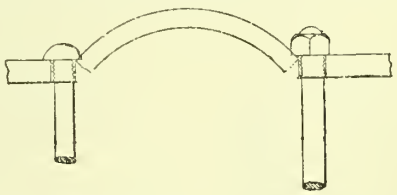


them multitubular; but in resorting to that construction you get many joints and you have also a voluminous structure. It occurred to me that a better result would be gained by rolling cylindrical bands of metal from solid steel ingots—cylinders of 1 foot in depth, and, as this drawing would show, 44 inches in diameter. In rolling metal in this fashion you get the whole strength of the metal in the right form for resisting a bursting strain. The difficulty was to make joints between the cylinders, and this was accomplished by turning in the face of each a V groove of about $\frac{1}{4}$ inch deep, rings of copper wire of $\frac{3}{8}$ inch thickness are thereupon placed between groove and groove, and the whole set of cylinders are screwed up and bolted together by sixteen or twenty long bolts made of steel of great elasticity containing about a $\frac{1}{2}$ per cent. of carbon, with a resisting power of about 50 tons to the square inch on the ends of the vessel. After screwing down these bolts hydraulic pressure was applied, and the vessel stood 1,300 pounds to the inch without a leak, but at that point a great many joints began to weep. The bolts were then drawn up $\frac{1}{8}$th of a turn, when the vessel was found to be perfectly tight at the pressure of 1,300 pounds, but the joints began to weep again at 1,400 pounds. We might have continued the operation of drawing up and have reached a higher limit of pressure, and seen whether all the parts of the vessel were not strong enough to resist 2,000 pounds to the inch, but inasmuch as the vessel in use was only to resist a pressure of 1,000 to the square inch, it was thought sufficient to tighten these bolts to the limit of 1,400 pounds, because we felt that if ever the pressure should reach that point the bolts would yield, owing to their elastic property, and allow the fluid within to escape, thus avoiding the risk of an explosion taking place. In that way vessels I believe can be constructed which are perfectly safe and capable of resisting a very high pressure. I may mention that in this form steel will bear a pressure of 45 tons to the inch with perfect ease and safety. It occurred to me therefore that marine boilers might be constructed on the same principle, by rolling a number of rings in this fashion and placing them one behind the other, with these copper rings inserted and bolting the whole down. In that way we should have at any rate a boiler shell capable of resisting 200 or 300 pounds pressure without the least risk of an explosion, whereas in riveting very heavy boiler plates of an inch in thickness there is always some difficulty in treating the material.

The CHAIRMAN: Gentlemen, I am sure you will all agree with me that we have had a most interesting, and allow me to add, most profitable Discussion. I am sure we are all very grateful to the author of this Paper, and he will allow us to thank him for having given us so valuable a contribution, and so good an example for the future. I am sure that we are equally indebted to those gentlemen who have been kind enough to take part in this Discussion. I hope you will not think that I have devoted too much of your time to the subject, because I think that we have got some very valuable information. I feel also that a very important remark was made by Dr. Siemens on this matter of punching steel plates, and as in that he expressed only a part of what is my belief in regard to it, I would call the attention of the author of the Paper to a question as to the mode of punching steel plates which I should not have troubled you with unless Dr. Siemens had hit on exactly the same idea. I will take this plate of Dr. Siemens' as he has drawn it, and I will suppose that you wish to punch that plate without injury to the steel. Allow me to tell you that I made all these experiments many years ago with iron for the purpose of using the iron without any injury, but I found the iron was injured by injudicious punching. I then tried to find out how I could punch the iron without injury. In order to do that I began to punch very thick plates with very small holes. Now I will tell you the result. The result of punching very little holes through a plate with sufficient power was that the plate always parted in a cone, spontaneously and freely. I therefore said to myself, surely if this mode of treating the plate in a cone is the mode which is most agreeable to the iron, and which leaves it in the best state, it would be wise to use that as the form of our punching holes, and it would be wise next to rivet our rivets into a hole of that shape. I now therefore venture to suggest to you to do the same thing in steel which I found of the greatest value in iron—namely, I ask you to make your punch of a given size and of a certain shape, to make your opening on the other side of a larger size—different degrees for the different kinds of metal—and my opinion is that you will arrive at some very beautiful cone which will be the best for each kind of steel you use; and my opinion is also that if you will take this opening and put a good rivet head there, and then simply well build up this hole with the point of the rivet, in the course of the riveting of the red hot rivet you will get everything in the most beautifully annealed condition immediately after, and you will have no more trouble on the point. I do not say you will find out this, for I am not a prophet, but I say that I found it so with iron, and I would seriously recommend it to your consideration in your experi-

ments. I can also give you one more little piece of information, in reply to a question that was asked; we have had very important experiments given to us on the construction of boilers made of flat plates united by square stays—stays square to their direction. Now allow me simply to say to you that I have tried boilers of the $\frac{1}{16}$th part of an inch thick, stayed at 3 inches apart with stays, I think, $\frac{3}{8}$ inch minimum diameter. I have put upon these nuts, inside and out, with washers, and I have proved these thin boilers to 240 pounds pressure, and found them perfectly safe. Owing to the thinness of the metal steam could be raised extremely rapidly, from the little impediment offered by the thin metal; and owing to the coolness of the metal produced by the vicinity of the cool water to the hot surface of the metal I have found them last for years without the slightest corrosion. Those are the only remarks that occur to me to add to what I consider a most valuable Discussion, for which I feel sure we are all extremely obliged. If there are any points upon which Mr. Parker could give us a conclusive answer we should be still more indebted to him.

Mr. William Parker (Member): The Chairman and Dr. Siemens have expressed themselves strongly in favour of employing a larger bolster in punching steel plates than is usually adopted, and while I concur generally in the statement that slightly conical punching produces less injury on the material than directly parallel holes, my experience does not quite bear out the supposition that the loss from punching diminishes exactly in proportion to the acuteness of the cone. In the series of comparative experiments to which allusion was made in my Paper we employed just an ordinary punch, but used bolsters of various proportions—in fact we went in some plates so far from the parallel as we could without the hole becoming jagged, and the result was that the loss to the material by taper punching was about 26 per cent. as compared with 33 per cent. That no doubt is a considerable difference and gives some ground for the belief that by the introduction of special patent punches we may ultimately be enabled to reduce this loss to practically nil; but still I think it would be misleading to assert without qualification that conical punching is entirely free from the injurious effects produced by ordinary punching. No doubt the circular shell plates of marine boilers will come to our hands rolled in one piece, but I do not think the arrangement of Dr. Siemens will be eventually carried out in its entirety. These long stays are no doubt admirably suited for a vessel to withstand water or air pressure, but when variations of temperature have to be taken into consideration, the joints would probably be found to leak in consequence of the unequal expansion and contraction. With regard to the question of stayed surfaces which has been raised by Mr. Wright and Mr. Kirk, and so fully gone into by Mr. Boyd, I may just give one or two particulars of the experiments we made. They were conducted in the first instance to ascertain the resistance of steel to buckle as compared with iron. We made the stays with riveted heads, the pressure was applied until the plate took something like the shape shown in the accompanying sketch, so that there was nothing left holding it except the small piece of head. If, instead of a riveted head a washer and a nut were used, that would practically be much stronger; but everyone who has had experience at sea with nuts in furnaces and combustion chambers knows that they give trouble, and last only a short time. The important point however is what is the most desirable distance to pitch these stays apart so that the plate may resist buckling, and retain the same factor of safety as the other parts of the boiler. As temperature must be taken into consideration in arriving at this conclusion, I have not before referred to these experiments, because, like Mr. Boyd's, they were not conducted under the influence of temperature, but when they have been so conducted as to give a really practical result I shall not fail to make them known. I was present at the experiment made with plain and corrugated furnaces to which Mr. Wright referred, and the corrugated flue expanded something like $\frac{1}{4}$ of an inch before it collapsed. Had its ends been attached as they would be in a boiler, I am inclined to think it would have resisted a greater pressure than it did on that occasion, the plain furnace did not elongate at all; if it had been secured at the ends it might also have stood a little more pressure. I am sure that these experiments prove that we have not had the factor of safety in plain flues that we supposed we had. As to the corrugations forming a receptacle for deposit, perhaps the best answer I can give to that is, that gentlemen who have had for ten or twelve years forty or fifty steamers to look after, and whose reputation depends on keeping them in good order with little expense, are confident that no trouble will be experienced from deposit, and are fitting several of their steamers with these furnaces; however, I shall from time to time have the opportunity of examining



these furnaces, and shall not fail to make known the actual results, experience alone being, in my opinion, the only means of solving this question.

Mr. KIRK: Will you allow me to say one word? Mr. Parker spoke of the thin plates being less affected by punching than the thick ones. I presume the thin plates and the thick plates were all punched by the same diameter of punch?

Mr. W. PARKER: No; different diameters.

Mr. KIRK: Was the diameter of the punch in proportion to the thickness of the plates?

Mr. W. PARKER: Yes, but not in exact proportion.

ON THE EFFECT OF DEPTH UPON THE STRENGTH OF A GIRDER TO RESIST BENDING STRAINS.

By F. P. Purvis, Esq., Associate.

[Read at the Nineteenth Session of the Institution of Naval Architects, 12th April, 1878; John Scott Russell, Esq., F.R.S., Vice-President, in the Chair.]

Among those interested in the question of the strength of a ship to resist bending strains the following opinion appears to be very generally held:—That the strength of a girder at any section is in all cases increased by a new disposition of some of its material at a greater distance from the neutral axis of the section; such a new disposition, for instance, as would be produced in a ship by raising the level of the upper deck, or by adding on to the topside plating, the new material being placed at a higher position than that already forming part of the section. The object of the present Paper is, firstly, to show that this opinion is not altogether correct—that there are cases in which a girder is weakened by an alteration of its section in the manner indicated; and, secondly, to give some quantitative results which shall serve to show whether a particular girder would be rendered weaker or stronger by such an alteration.

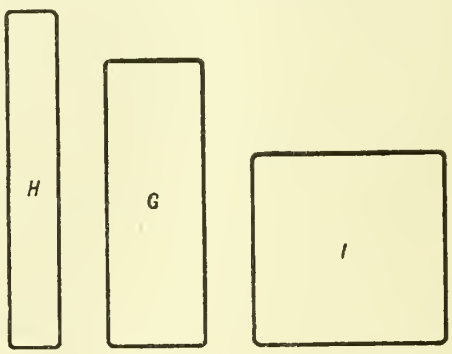
Supposing a girder, such as A, to consist of two flanges, and of a web of sufficient thickness only to connect the flanges and to transmit the strains from one to the other, but of sectional area small enough to be neglected in comparison with that of the flanges; in such a structure any change in the relative position of the flanges in the direction away from each other, and therefore away from the neutral axis, would certainly give strength against bending, for the strength of each flange may be measured approximately by the product of its sectional area into the distance from centre to centre of the flanges, and the strength of the girder is therefore in direct proportion to the distance between the flanges. It seems to be the consideration of this fundamental case which has led to the erroneous conclusion I am considering.

Before proceeding further to girders of less simple construction, it is necessary to state the conditions upon which, in this Paper, I have considered the comparative strength of girders to depend. It might indeed be looked at from two points of view; one their strength as a whole—that being considered the stronger girder which would maintain the greater load without fracture right through; the other their strength as regards the most severely-strained portion—that being considered the stronger girder which would maintain the greater load without fracture at any part. These two views may be illustrated by the comparison of the girder of section B with that of section C;

according to the second C would be the weaker section, because the portion $r\,s$ would begin to tear under the action of a load which would be insufficient to injure B; while according to the first view C would be the stronger, because after the rupture of $r\,s$ the dimensions of the remaining portion would be such as to enable it to bear a greater load than B without further injury. Now, in a ship, it is important, not only that the section should be strong enough as a whole, but that it should be free from rupture at any part. I have therefore adopted the second of the above-mentioned views, and have considered the stronger section to be the one which would encounter the greater bending moment without beginning to fracture at any part; in other words, the one which under the action of a given bending moment would experience the less strain at its more severely-strained part.

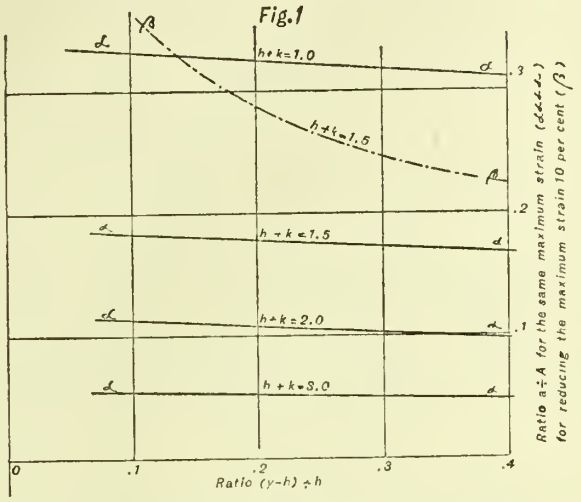
As I have stated, the section C is, according to the view of strength adopted, weaker than the section B. Quantitatively, it might be readily shown that if the portion $s\,t$ had the same depth and breadth as B, and the portion $r\,s$ had half the depth of B, and a breadth small in proportion to that of B, the maximum strain under a given bending moment would for C be approximately double what it would be for B.

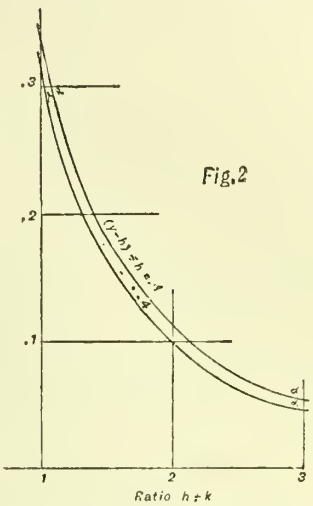
This then is one case in which deepening introduces weakness rather than strength. To take another, more nearly resembling that of an actual ship, let two box girders be considered, of the same perimeter, having the sections G and H respectively; let the thickness of the plate be uniform and the same in each, so that the sectional area of the two sections is the same; it may be easily found that the maximum strain under a given load is some 3 per cent. less for G than it is for H, so that the form G gives a stronger section than the form H. It is, however, to be remarked that the form G is also stronger than the form I, the maximum strain being some 12 per cent. less for G than for I, under the action of the same bending moment. Indeed the perimeter of the section being fixed, it is a problem of easy solution to determine the ratio of depth to breadth which will give the strongest section to resist bending; that ratio is 3:1, and is the ratio used in constructing the section G.



Having shown by these particular cases that the strength of a girder is not necessarily increased by an increase in its depth, the total area of section being kept the same, I proceed to give some quantitative results. In obtaining these I have supposed the new disposition to take place on one side of the neutral axis only (call it the upper side for convenience), and have considered the strength of the girder on that side of the neutral axis on which the change of disposition takes place, regarding the strength on the other side to be amply sufficient not to require any consideration. I have also supposed the sectional area for the new portion to be derived from the top flange of the girder, and to be formed into a new horizontal flange; and further, have made no allowance for the web connecting this new flange with the girder (later in the Paper, however, I have mentioned a correction for this omission). The results are exhibited by the accompanying curves, Figs. 1 and 2 (the construction of which is explained in an Appendix). The letter h signifies the distance from the neutral axis of the most distant part of the section before the alteration, on that side which

is under consideration; y the distance from the original neutral axis of the most distant part after the alteration; k the radius of gyration of the section before alteration, *i.e.*, the square root of the quotient of the moment of inertia by the sectional area; A* the total sectional area; a the sectional area of the part shifted; so that the part a is supposed to be shifted from a distance h, to a greater distance y, from



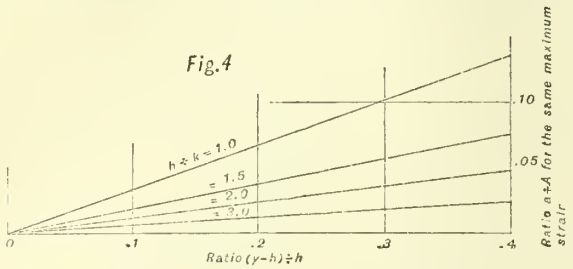


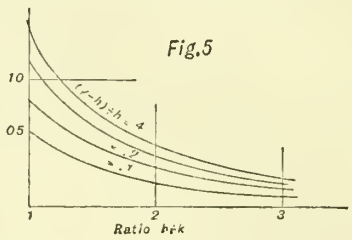
the original neutral axis. The curves give the ratio which must exist between a and A in order that the shift shall neither strengthen nor weaken the section. This ratio depends upon two others, the ratio of y to h, or of $y - h$ to h, and the ratio of h to k. To take an example of the use of the curves on Figs. 1 and 2, suppose the sectional area for a given ship to be 1,200 square inches, the radius of gyration for the section to be 10 feet, and the distance from the neutral axis of the furthest part of the section (say the upper deck) to be 15 feet; let it be desired to know the least amount of area that that upper deck must possess in order that its shift from a distance of 15 feet from the neutral axis through a distance of 3 feet may neither increase nor decrease the strength of the section. From the values given $\frac{h}{k} = 1{\cdot}5$, $\frac{y-h}{h} = 0{\cdot}2$. Looking on Fig. 1 at the ordinate of the curve marked $h \div k = 1{\cdot}5$, opposite the abscissa 0·2, the value of $\frac{a}{A}$ is given as 0·17; so that in order to give neither more nor less strength to the upper part of the ship, 204 square inches must be shifted in the manner assumed. If in shifting the area it is intended to add strength to the beam, then an amount must be shifted greater than that given by the curves; if less is shifted, then the beam instead of being made stronger will be made weaker. The amount to be shifted in order to increase the strength in a given proportion will be recurred to directly.

In what has gone before, it has been assumed that no extra area is brought into the section, but that only that already present is shifted. If we now assume that the section is unaltered except that new area is introduced into it at the distance y from the neutral

* The values of A and a are taken primarily for sections in which the material is the same throughout, wood or iron for instance; if the section be partly wood and partly iron, one material must be reduced to its equivalent value in the other; this may be done, approximately, by reducing the area of the wood in the ratio of 16 : 1.

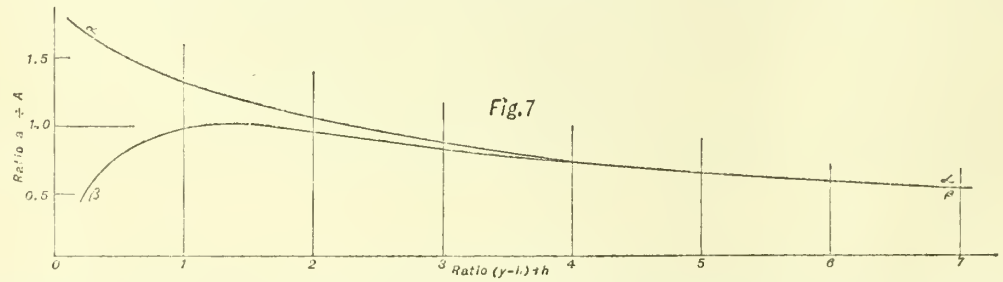
axis, this sectional area, neeessary just to maintain the same strength as before will be eonsiderably less than in the ease just eonsidered. The ratio $\frac{a}{A}$ under this condition is shown by the curves on Figs. 4 and 5, the letters having the same meaning as before.





Taking for an example the same figures as in the previous case, and looking at the curve marked $h \div k = 1{\cdot}5$, for the ordinate whose abseissa $\left(\frac{y-h}{h}\right) = 0{\cdot}2$, we find that $\frac{a}{A} = 0{\cdot}047$, so that a must equal 56 square inches, in order that the beam shall neither gain nor lose in strength; and as before the value of a must be greater than this if it is to gain.

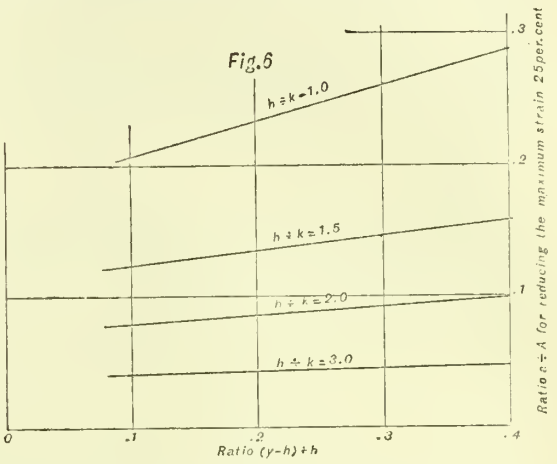
As the tendency of the curves at the point for which $\frac{y-h}{h} = 0{\cdot}4$ (the maximum given in Figs. 1 and 4), might give a wrong impression as to the value of $\frac{a}{A}$ for higher values of $\frac{y-h}{h}$, I have shown on Fig. 7, on a smaller horizontal scale, the value of $\frac{a}{A}$ for values of $\frac{y-h}{h}$ up to 7 (the value of $\frac{h}{k}$ being throughout 1·5); of the



two curves $\alpha\alpha$ represents the ease of area shifted in the section merely, $\beta\beta$ the case of new area introdueed. The two eurves, although they never really coincide, are asymptotic, and lie close together for eomparatively small values of $\frac{y-h}{h}$.

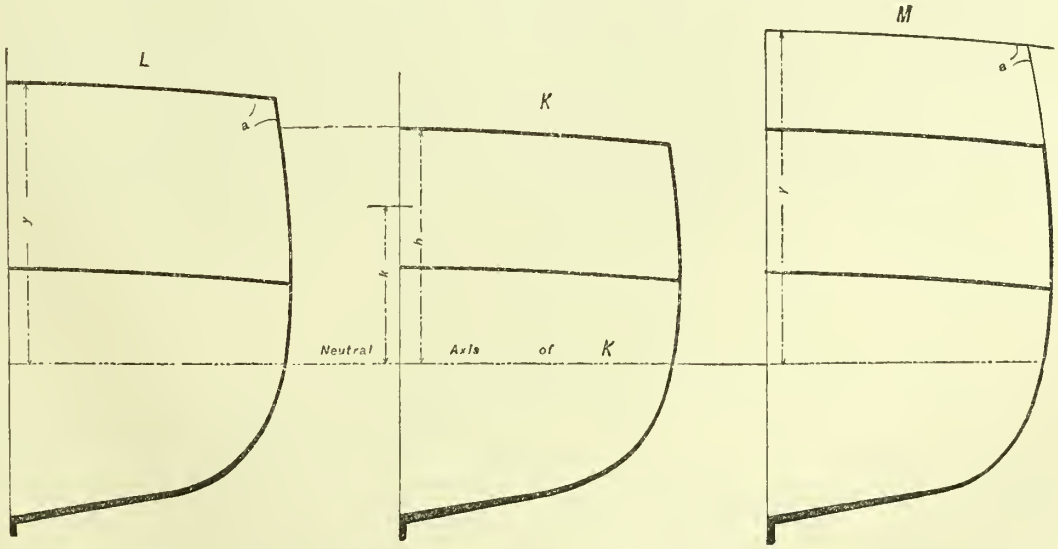
Suppose now that it is required to shift some of the material of a given section in sueh a way that, instead of the greatest strain produeed by a given bending moment remaining the same as before, it may be diminished by a definite amount, say 10 per cent.; let the ratio $\frac{h}{k}$ be 1·5, which is perhaps about an average value for most ships. The value of $\frac{a}{A}$, necessary to give the result required, in terms of $\frac{y-h}{h}$, is given by the eurve $\beta\beta$ on Fig. 1; in this ease the value of a, amounting to from $\frac{1}{5}$th to $\frac{2}{5}$ths of A, is so large that in all probability the whole of the upper flange of the

girder would not satisfy it, and material would have to be moved from distances nearer to the neutral axis. The curve would only approximately apply to such a case, but possibly the course adopted would be to introduce new material. Suppose new material to be introduced; the curves become those shown on Fig. 6. In this case, however, it is supposed that a diminution of 25 per cent. is required to be made in the maximum strain caused by a given bending moment. If a diminution less than this be required it may be obtained approximately by interpolating between the values given by the curves on Fig. 4 and those given by the curves on Fig. 6.



It must be borne in mind that, in constructing these curves, no allowance has been made in any case for a web to connect the new flange to the girder. This defect may be approximately remedied in the case of material shifted by taking a to include half the area of that web; and in the case of new material added by taking a to include the area of the web diminished in the ratio of y to $\frac{y+h}{2}$.

In order to show more fully the use of the curves, and also the points to be considered in applying them, let us consider a little further the possible alterations in the imaginary ship already quoted for purposes of illustration—the ship, that is, shown in section by K and having a sectional area at midships of 1,200 square inches, a radius of gyration of 10 feet, and the height of its upper deck above the neutral axis 15 feet. First let the effect be considered of raising the upper deck through 3 feet,



as shown by the section L, without altering the sectional area of the material, the area for the new strake of plating being obtained by reducing that of the deck. Let

the area of the deck be 200 square inches (taking the wood as equivalent to $\frac{1}{16}$th of its area in iron), and let the thickness of the new strake of plating be $\frac{3}{4}''$; the sectional area of that new strake will be 54 square inches, thereby reducing the area of the shifted deck to 146 square inches. Taking one half of the value of the web along with that of the deck after the shift, 173 is the result. Now the value of $\frac{y-h}{h}$ is 0·2, the value of $\frac{h}{k}$ is 1·5, and from the curves shown on Fig. 1 we get that the value of $\frac{a}{A}$ must be 0·17 to make the maximum strain on the section L the same as on K, 0·282 to make that maximum strain 10 per cent. less; the necessary value of a being therefore 204 square inches in the former case, 338 square inches in the latter. But the value obtained by the actual shift is 173 approximately; so that the section instead of being strengthened is subjected to a maximum strain about $2\frac{1}{2}$ per cent. greater after the shift than it was before.

Next suppose a new deck added instead of the upper deck being shifted in the way last considered. Let it be placed, as shown by the section M, at a height of 6 feet above the existing deck, and let its sectional area be 100 square inches. Let the thickness of the side plating below this deck be $\frac{1}{2}$ inch, its area will then be 72 square inches, which reduced in the ratio of y to $\frac{y+h}{2}$ becomes $72 \times \frac{15+21}{21 \times 2} = 62$; adding this to the area of the new deck we have a value of 162 square inches for comparison with the results given by the curves. As before $\frac{y-h}{h} = 0{\cdot}4$; $\frac{h}{k} = 1{\cdot}5$. Referring, then, to Figs. 4 and 6, we see that the area necessary to give the same maximum strain $= 0{\cdot}074 \times 1{,}200 = 89$ square inches, while the area necessary to give 25 per cent. diminution of maximum strain $= 0{\cdot}162 \times 1{,}200 = 194$ square inches. So that by the introduction of the new deck a diminution of some $17\frac{1}{2}$ per cent. is brought about in the maximum strain upon the section due to a given bending moment.

In any application which may be made of the curves it is necessary to notice in what particulars the conditions of the case under consideration differ from the assumed conditions upon which the curves are based, and to make allowance for the difference. The curves are by no means intended to give absolute results under all circumstances; they are rather meant to give the designer, who finds his ship too weak, and has the opportunity of making certain small alterations, some notion as to whether those alterations will produce the desired effect.

APPENDIX.

The object of this Appendix is to give the construction of the curves made use of in the foregoing Paper.

The simplest case is that in which new material has been added to the section under consideration: I will show first how the curves dealing with that case have been constructed. Giving to the letters the same meaning as they have in the Paper, and expressing the strain upon the part distant h from the neutral axis before the alteration by p_1, and the bending moment on the section by M, the following equation holds between the quantities:—

$$\frac{p_1}{M} = \frac{h}{Ak^2}.$$

Now placing new material a at the distance y from the original neutral axis raises that neutral axis through $\frac{ay}{A+a}$, and increases the moment of inertia of the section by $ay^2-(A+a)\frac{a^2y^2}{(A+a)^2}$; so that if, in the new arrangement, p_2 represents the strain upon the part distant y from the original axis,

$$\frac{p_2}{M} = \frac{y - \frac{ay}{A+a}}{Ak^2+ay^2-(A+a)\frac{a^2y^2}{(A+a)^2}}.$$

In order that p_2 may be equal to p_1, M being the same in the two equations, we must have—

$$\frac{h}{Ak^2} = \frac{y - \frac{ay}{A+a}}{Ak^2+ay^2 - \frac{a^2y^2}{A+a}};$$

whence

$$\frac{a}{A} = \frac{y-h}{h} \times \frac{k^2}{y^2+k^2}.$$

From this equation the curves given on Figs. 4 and 5 were obtained. For instance, suppose $\frac{y-h}{h} = 0{\cdot}2$; and $\frac{h}{k} = 1{\cdot}5$; then $\frac{y}{k} = 1{\cdot}2 \times 1{\cdot}5 = 1{\cdot}8$,

and

$$\frac{k^2}{y^2+k^2} = \frac{1}{1+(1{\cdot}8)^2} = \frac{1}{4{\cdot}24}$$

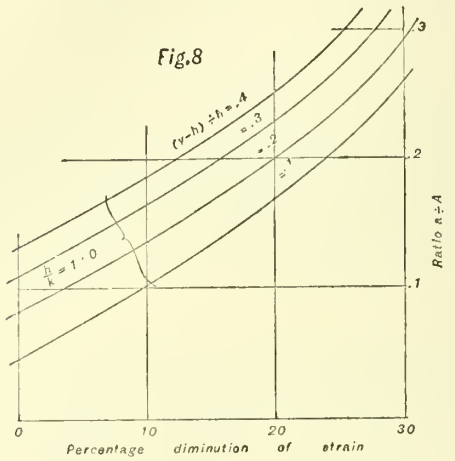
so that

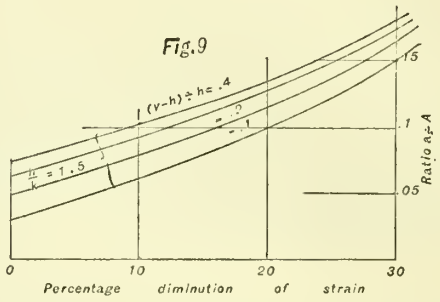
$$\frac{a}{A} = \frac{0{\cdot}2}{4{\cdot}24} = {\cdot}047,$$

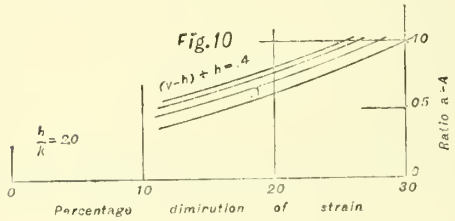
which will be found to agree with the curves.

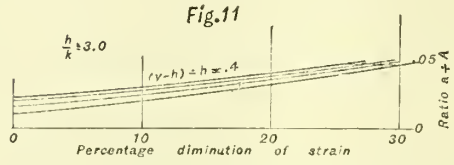
Next for the construction of the curves shown on Fig. 6. It seemed most convenient to work out for several values of $\frac{a}{A}$ what would be the diminution of strain according to the value of $\frac{y-h}{h}$ and $\frac{h}{k}$; to make curves, which are given in Figs. 8 to 11, showing this

diminution in the form of a per-centage, and to obtain the curves shown on Fig. 6 from these curves, by taking those values of $\frac{a}{A}$ only, which correspond to a diminution of









strain of 25 per cent. Before the alteration of the section, the maximum strain is given by $\frac{p_1}{M} = \frac{h}{Ak_2}$; after the alteration by $\frac{p_2}{M} = \frac{y - \frac{ay}{A+a}}{Ak^2 + ay^2 - (A+a)\frac{a^2y^2}{(A+a)^2}}$;

so that
$$\frac{p_2}{p_1} = \frac{\frac{y}{h}\left(1 - \frac{a}{A+a}\right)}{1 + \left\{\frac{a}{A} - \frac{a^2}{A(A+a)}\right\}\frac{y^2}{k^2}}$$

$$= \frac{\frac{y}{h}\left(1 - \frac{a}{A+a}\right)}{1 + \frac{a}{A+a}\frac{y^2}{k^2}}.$$

Suppose
$$\frac{h}{k} = 1{\cdot}5; \quad \frac{y-h}{h} = 0{\cdot}2; \quad \frac{a}{A} = 0{\cdot}1;$$

then
$$\frac{p_2}{p_1} = \frac{1{\cdot}2\,(1 - \frac{1}{11})}{1 + \frac{1}{11} \times 5{\cdot}24} = \frac{84{\cdot}3}{100};$$

so that p_2 is 15·7 per cent. less than p_1; a result which will be found to agree with the curve marked $\frac{y-h}{h}=0{\cdot}2$ on Fig. 9. In the same way other points of the curves were determined, and the curves shown on Fig. 6 were obtained from them by taking the values of $\frac{a}{A}$ corresponding to the abscissa representing 25 per cent., and setting those values off according to the values of $\frac{h}{k}$ and $\frac{y-h}{h}$. It will be seen that the curves on Figs. 8 to 11 give the means of constructing curves showing the proportion $\frac{a}{A}$ to give any diminution of strain less than 25 per cent.; indeed the values of $\frac{a}{A}$ at the point where the abscissa is 0 give also the data for the curves on Figs. 4 and 5, the construction of which by a more direct method has already been explained.

Take next the construction of the curves shown on Figs. 1 and 2. In this case the value of p_1 is still given by—

$$\frac{p_1}{M}=\frac{h}{Ak^2},$$

while p_2 is given by—

$$\frac{p_2}{M}=\frac{y-\frac{a(y-h)}{A}}{Ak^2+a(y^2-h^2)-A\frac{a^2(y-h)^2}{A^2}}.$$

As p_2 is to be equal to p_1,

$$\frac{h}{Ak^2}=\frac{y-\frac{a(y-h)}{A}}{Ak^2+a(y^2-h^2)-A\frac{a^2(y-h)^2}{A^2}},$$

which gives a quadratic for the value of $\frac{a}{A}$. The solution of the quadratic is—

$$\frac{a}{A}=\frac{y+h+\frac{k^2}{h}}{2(y-h)}\pm\frac{\sqrt{\left\{y^2+h^2+\frac{k^4}{h^2}+2hy-\frac{2k^2y}{h}+6k^2\right\}}}{2(y-h)}$$

or,

$$\frac{\frac{y}{h}+1+\frac{k^2}{h^2}\pm\sqrt{\left\{\frac{y^2}{h^2}+1+\frac{k^4}{h^4}+2\frac{y}{h}-\frac{2k^2y}{h^3}+6\frac{k^2}{h^2}\right\}}}{\frac{2(y-h)}{h}},$$

in which the minus sign is evidently the one to be taken. Let $\frac{y-h}{h}=0{\cdot}2$, $\frac{h}{k}=1{\cdot}5$, as before;

then

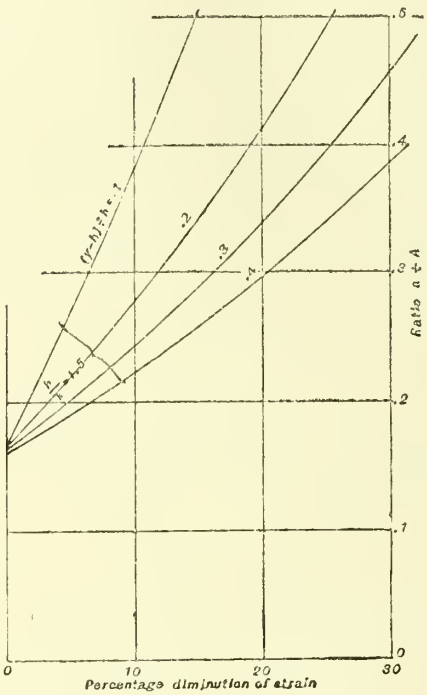
$$\frac{a}{A}=\frac{1{\cdot}2+1+\left(\frac{1}{1{\cdot}5}\right)^2-\sqrt{\left\{1{\cdot}44+1+\left(\frac{1}{1{\cdot}5}\right)^4+2{\cdot}4-\frac{2{\cdot}4}{(1{\cdot}5)^2}+\frac{6}{(1{\cdot}5)^2}\right\}}}{\cdot 4}$$

$$=0{\cdot}170,$$

a result again which will be found to agree with the curves.

Lastly, for the curve $\beta\beta$ on Fig. 1, the method used for its construction was analogous to that used for the curves on Fig. 6. The curves shown on Fig. 12, giving the per-centage diminution of strain in terms of the value of $\frac{a}{A}$ for different values of $\frac{y-h}{h}$, were first constructed, and the values of $\frac{a}{A}$ of these curves corresponding to the abscissa

Fig. 12



10 per cent. were then used for the curve in question. As in the case of new material added, curves for other per-centages besides 10 may be obtained from Fig. 12, the ordinates, for instance, corresponding to the abscissa 0, giving the necessary data for the curve marked $\frac{h}{k} = 1{\cdot}5$ on Fig. 1.

DISCUSSION.

Mr. William John (Member of Council): I should like to say a few words in testimony of what I think is the value of this Paper. I think it carries out a line of thought that must have struck many of us at various times, and Mr. Purvis deserves great credit for having carried it to the extent he has. In a few words I will endeavour to show how it appears to me it occurs in practice. Suppose we have a ship of a certain depth and width and we want to put a light super-structure over that vessel. Now it is difficult to make people see sometimes that you should make that super-structure so light, that, although you are adding material to the vessel and you are not diminishing the strength of the hull proper at all, yet if you make the super-structure continuous fore and aft, you invariably make that the top of your girder and expose it to strains more severe than the original upper-deck ship would have been. It is a

question that often arises—whether, if you want the super-structure only a very light one, it is not infinitely better that you should sever that super-structure at different parts of the length of the ship to prevent its taking the longitudinal strain and taking at an undue degree, than that you should carry it right fore and aft. There are two or three different courses to adopt—either you can make the superstructure strong enough to bear its proper share, or sever it and make it a local thing not taking part in the construction of the ship, or you can make the ship below sufficiently strong to carry the superstructure.

The CHAIRMAN (Mr. John Scott Russell, F.R.S.): To throw no strain upon it.

Mr. W. JOHN: I will not go into the matter further than that. From a particular point of view it is a line of thought which has been worked out by Mr. Purvis to an extent to which I do not think it has ever been worked out before; and I therefore beg to thank Mr. Purvis for the trouble and labour he has bestowed upon this Paper.

Mr. WILLIAM DENNY (Member of Council): I have very much pleasure in adding my testimony to that of Mr. John with regard to the value of the Paper. Mr. John has pointed out that it is specially advantageous in the consideration of the construction of an ordinary merchant ship to which a light superstructure is to be added; but it is also advantageous in other constructions which very often come into the hands of the shipbuilder. If I am not mistaken this Paper had its origin in the consideration of such constructions as we have to do with in light-draught river steamers, where we have a very small weight of iron at our disposal and very little power to add more without injuring the steamer in the matter of draught. In that case we are compelled to seek every possible method of using the iron to the best advantage. It must be well known to every Member of the Institution that this is the crux which has puzzled our friends on the other side of the Atlantic, and which they have in many cases solved. It is a crux to us on this side of the Atlantic in cases of river steamers, and where we wish to apply a girder within the hull, or a lattice girder beyond the hull, or in such a utilization of a flying deck or awning roof as Mr. James Napier managed in one of his steamers. In such cases we have problems before us to which Mr. Purvis has supplied a key. It is a great pity that Mr. Purvis in this Paper did not add to his theoretical investigations a note as to their practical application. I can only believe in this matter that he has done injury to himself by his own modesty. I sincerely trust we shall see Mr. Purvis come still more before this Institution. He is a Royal Naval Schoolman, and I feel it a very great pleasure he is on the Clyde. I desire that we may have many more like Mr. Purvis on the Clyde, and that they may contribute to the influence of this Institution.

Mr. A. C. KIRK (Member): Mr. John and Mr. Denny have completely taken the wind out of anything I can say. I have great pleasure in endorsing everything that has been said on the subject. Mr. Purvis has drawn our attention to a matter that ought very frequently to be looked at in all structures, engine work, ship work, and all. The case referred to by Mr. John has come before me in my own experience more than once, as no doubt it also has in Mr. Denny's. For instance I once had to object to a proposal to strengthen a broad shallow ship with an iron deck, by adding on the top of it deep bowstring girders. Had it been done the bow girder must have been made equal to take the entire strain, and the iron deck would have been entirely relieved. There are a great many cases where we are in the habit of counting a tensional strain over a whole section of plate. In many cases when fairly looked at it is very doubtful whether the strain is uniformly distributed over the whole section of plate. Although Mr. Purvis has not taken it up, there is another case which has often struck me about girders, which might be worthy of his attention, for it surpasses my mathematical powers to solve. When you have a girder with a top member of abnormal breadth, connected to the lower member by two sides, and you have a set of tensional strains applied along it, say by lattice-bar sides, what is the strain per square inch across this girder? Take the broad deck of a ship for instance. What is the tensile strain across the breadth of it? We know quite well, as a matter of fact and experience, that they begin to tear at the two edges when the strains are applied, and therefore the strains evidently are greater there. This is almost an illustration of what Mr. Purvis has done, and we find the same thing in a great many other cases. I think Mr. Purvis has done great service to us. I do not speak of the mere technical and mechanical part of his Paper where he has drawn these plans to facilitate the special calculations, but he has done very great service in drawing attention to the matter. He might have dwelt more fully, I think, on the necessity of watching carefully whether the strains of the material are distributed or concentrated at one end, and the fracture comes in a gradual manner.

The CHAIRMAN: I think, Gentlemen, at this hour of the night there remains only one duty, and that is for us to say how much obliged we are to the author of this Paper for the new views he has laid

with such admirable clearness before us; and I can only add my testimony to the fact that the problems which he refers to are problems which occur very frequently, and which have occurred most frequently probably to those who, like some of us, have had the trouble of constructing very long steamers, to draw very little water, and to stand very heavy strains. Those are very often the nearly impossible problems which are submitted to the shipbuilder. I think they are treated here very admirably and show what some of us will acknowledge—that we very often are induced to add pieces of material to one part of a ship with a view and with a belief that in putting on these annexes we add to the strength of the ship, whereas by putting on these annexes some additional material, which material is subject to strains greater than it can homogeneously bear, we simply create points of weakness in the structure where we meant to create points of strength. We are, I think, much indebted to this gentleman for his excellent Paper; and I can only join in the hope expressed that, although this is the first, it will not be the last of the Papers we shall have the pleasure of listening to from him.

NOTE ON THE FACT—That in any Compound Engine there is a Definite Ratio of Expansion which gives a Maximum Value for the Mean Pressure on the High-Pressure Piston.

By J. C. Spence, Esq., A.I.N.A., Superintending Engineer, India General Navigation Company Limited.

[Read at the Nineteenth Session of the Institution of Naval Architects, 12th April, 1878; John Scott Russell, Esq., F.R.S., Vice-President, in the Chair.]

The work expended in reversing the motion of the piston at each end of its stroke, and in friction between the piston and cylinder, depends on the dimensions and velocity of the piston, but is independent of the pressure on it. Therefore the ratio between useful work and total work is greatest when the pressure on the piston is greatest.

Also the greater the pressure on the piston the smaller it is required to be, in order that it may do a given amount of work—that is to say, economy in working and in first cost increase (other things being equal) as the pressure on the piston is increased.

If, therefore, in a compound engine there is a definite rate of expansion in the high-pressure cylinder, which gives a maximum value for the mean pressure on its piston, then that rate of expansion is the most economical in working and in first cost, and should be adopted for the normal working of any engine, unless there are special reasons of greater importance than the above for using some other rate of expansion.

To determine the ratio of expansion which will give this maximum pressure is the object of this Paper.

In Fig. 1.

Let A B	represent	the volume of	high-pressure cylinder	$= V$
„ A D	„	„	low „	$= V \times m$
„ A g	„	„	occupied by the steam when H.P. valve cuts off	$= \frac{V}{r}$
„ A C	„	„	„ „ „ L P. „ „	$= V \times n$
„ A E	„	„	initial pressure of the steam ...	$= P_1$
„ G H L N	„	the expansion curve for steam expanding from volume A g to volume A D.		

Let L M be drawn through L parallel to A D, then M K would represent the line of back pressure on the high-pressure piston, if the volume occupied by the steam between the high and the low-pressure cylinders were indefinitely increased.

If we assume that the pressure of steam varies inversely as its volume, then the back pressure would be—

$$P_b = L C = P \cdot \frac{A g}{A C} = P_1 \frac{\frac{1}{r}}{n} = P_1 \times \frac{1}{r \times n}$$

And the area, E G H K M, representing the work done per stroke, equals—

$$\text{E G H B A} - \text{A B K M} = \text{P}_1\text{V}\left\{\frac{1+\log r}{r}\right\} - \text{P}_b\text{V} = \text{P}_1\text{V}_1\left\{\frac{1+\log r}{r} - \frac{1}{rn}\right\}$$

And this expression has a maximum value when r is determined by the equation $\log_e r = \frac{1}{n}$. And for this value of r the work done per stroke $= \frac{\text{P}_1\text{V}}{r}$.

In Fig. 1. the area H K L represents the loss due to expansion of steam in the passages and receiver between the high and the low-pressure cylinders, and this becomes = O when the cut-off in the low-pressure cylinder is so arranged that C coincides with B, that is when $n = 1$; in this case $\log_e r = 1$.

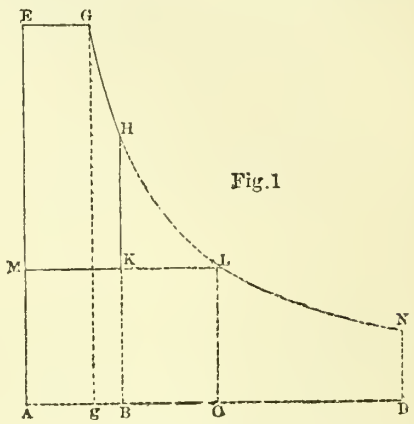


Fig.1

$$\therefore r = e = 2{\cdot}718.$$

If, therefore, we consider the diagram of an engine to be made up of straight square lines and true expansion curves, we find that the mean pressure on the high-pressure piston is a maximum when r the rate of expansion satisfies the equation $\log_e r = \frac{1}{n}$, n being the ratio between the volume of the steam when it leaves the high-pressure cylinder, and its volume when it is cut off in the low-pressure cylinder. And when $n = 1$, which proportion is the most economical of steam, although it is not generally adopted, then r should be equal to 2·7.

The above formula cannot be said to apply exactly to actual working engines, but it will be found to be a very close approximation to the truth, if we consider the action of the principal disturbing causes, upon the diagram.

The line of back pressure differs from the assumed parallel straight line in form, but the mean pressure of the actual line is a very near approximation to the back pressure we have assumed.

The loss, from wire drawing in the valves and passages, from early release of the steam and from cushioning, &c., may be considered as a constant fraction of the whole work, and will not greatly affect the relation between forward and back pressure.

To illustrate this numerically the diagrams, Figs. 2, 3 and 4, have been drawn for an engine having the cylinders in the ratio of 4 : 1, cutting off at half-stroke in the low, and with an intermediate space = the volume of the high-pressure cylinder. Here as the cylinders are 4 : 1 and the low pressure cuts off at half-stroke $n = 2$, and according to the foregoing theory the mean pressure should be a maximum when $\log_e r = \frac{1}{2}$—

$$i.e., r = 1{\cdot}65.$$

$$\text{The cut-off being } \frac{1}{r} = \frac{1}{1{\cdot}65} = {\cdot}6 \text{ of the stroke.}$$

And we find that with an initial pressure of 80 lbs. absolute we get in—

Fig. 2	where the cut-off is	·5	of the stroke,	the mean pressure	43·9 lbs.
Fig. 3	„	„	·6	„	„	45·4 „
Fig. 4	„	„	·7	„	„	44·0 „

The pressure being greater in Fig. 3 than in Fig. 2 or Fig. 4.

From these considerations I believe we are justified in concluding that in any compound engine there is a certain cut-off, depending chiefly on the ratio between the volume of steam when it leaves the high-pressure cylinder and its volume when it is cut off in the low-pressure cylinder, which gives a maximum value to the mean pressure on the high-pressure piston, and that after that point has been reached the back pressure increases faster than the forward pressure, and consequently the effective pressure diminishes the further the steam is carried beyond this point.

Fig. 2

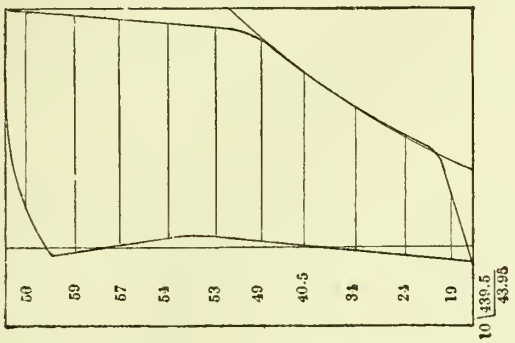


Fig. 3

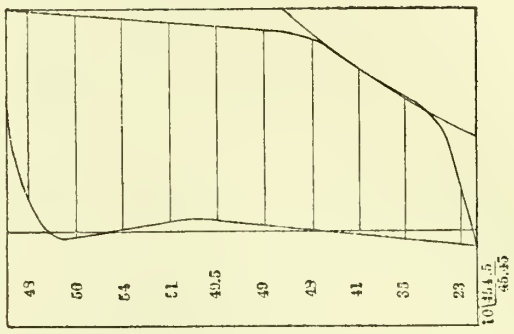
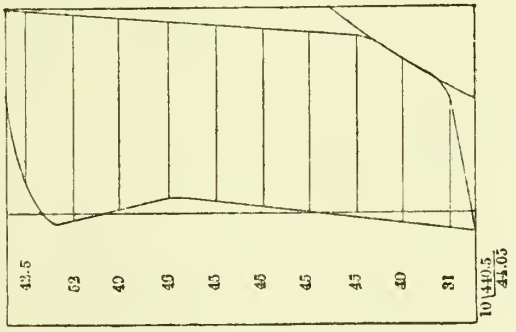


Fig. 4



PROCEEDINGS ON APRIL 13TH.

The PRESIDENT: Before I call on Mr. White to read the first Paper, it is my duty to state to the Meeting that there has been a Council held this morning, and I will state what was done at that Council. One thing done that I hope will meet with the unanimous concurrence of all the gentlemen present was, that we should request the First Lord of the Admiralty to join us as one of our Vice-Presidents. I am very happy to say that previous First Lords, ever since the Institution commenced, have always been on the list of our Vice-Presidents, and I think that everybody would desire that the present First Lord of the Admiralty should also be so appointed. The Council have requested me, subject to your approbation, to communicate to the First Lord the wish we feel on this subject, and to request his concurrence. I have also been desired to request Mr. Brassey, who is a very distinguished Member of our associate body, to become an Associate Member of Council. There is also another Resolution which the Council have arrived at this morning, which is, that hereafter it is desirable that new Members and Associates should pay an entrance fee in addition to their first year's subscription, of the same amount, namely two guineas. I have now only to request the concurrence of this Meeting in these decisions of the Council.

[The Resolutions having been put to the Meeting by the President, were carried unanimously.]

NOTE ON THE GEOMETRY OF METACENTRIC DIAGRAMS.

By W. H. White, Esq. (Member of Council), Assistant Constructor of the Navy, and Instructor in Naval Architecture, Royal Naval College, Greenwich.

[Read at the Nineteenth Session of the Institution of Naval Architects, 13th April, 1878; the Right Hon. Lord Hampton, G.C.B., D.C.L., President, in the Chair.]

Metacentric diagrams are now so generally used as a convenient means of graphically recording variations in stiffness accompanying changes in the lading and draught of water of ships, that I need not attempt any explanation of their method of construction. The limits of *load* and *light* draught are obviously those within which such curves can be put to any practical use, and they are usually only constructed over such a range of vertical displacement as will ensure accuracy for the metacentric curve within those limits of draught. On the other hand, the geometrical properties of the *loci* of the centre of buoyancy and the metacentre are quite independent of these limits, and the object of the present Paper is to state briefly one or two of these properties, which have not, so far as I am aware, yet been stated, and which may have some interest for the student, even though they have but little practical value.

It is scarcely necessary to say that the great varieties existing in the under-water forms of different types of ships produce corresponding variations in the forms of the curves shown on the metacentric diagrams, and that it is not safe to infer from a similarity of shape in the midship sections of two ships that the curves on the metacentric diagrams will be similar, since there may be considerable differences in the forms of the respective transverse sections towards the bow and stern. A few examples of the metacentric diagrams for actual ships will be the best evidence of these general statements.

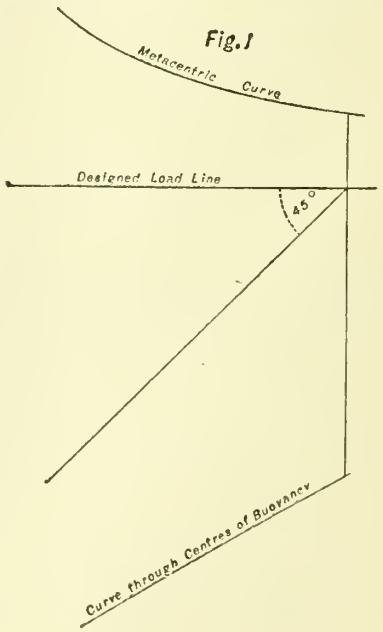


Fig. 1 shows a very common case for war ships of ordinary form. The curve through the centres of buoyancy is nearly a straight line, and the metacentric curve gradually rises from the load towards the light draught.

Fig. 2 illustrates the condition of a vessel of the Symondite type, with "peg-top" bottom. The metacentric curve is here concave to a horizontal line, and its height in relation to the curve through the centres of buoyancy decreases as it passes from load to light draught.

Fig. 3 illustrates the condition of a vessel like the *Inconstant;* here the metacentric curve is nearly horizontal, but drops slightly as it passes from load to light draught. The *Captain* had a very similar metacentric curve.

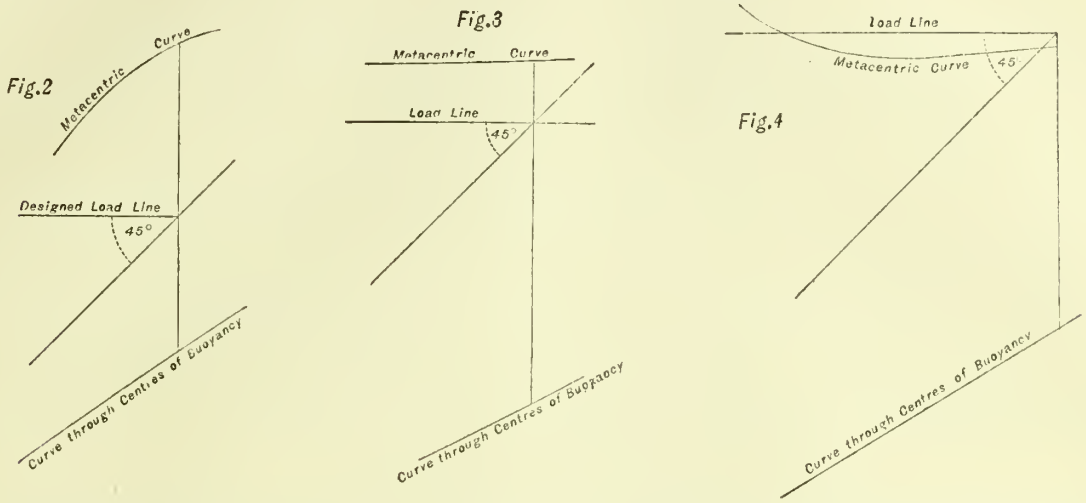


Fig. 4 shows a case where the metacentric curve drops slightly as it passes from the load draught towards a lighter draught; then has a horizontal tangent, and afterwards rises as it passes to the lighter draught.

There are other varieties in these metacentric curves, but I need not illustrate them. The calculations necessary to their construction are so simple that any attempt to dispense with calculations, by generalisations as to the forms of metacentric curves, would be as ill-advised as the previous diagrams show it might be dangerous. For prismatic bodies of regular forms it is, of course, easy to obtain equations for the metacentric curves, and some interesting work of this kind will be found in a Paper contributed by Mr. G. Stanbury to the *Annual* of the School of Naval Architecture for 1872. For ships similar equations cannot be found, nor are they required.

The first subject to which I wish to direct attention is the determination of the conditions under which the tangent to the metacentric curve at any point can become *horizontal.* In very many cases no such horizontal tangent can be drawn within the limits between load and light draught, but in nearly all metacentric curves such a "turning" point or points will exist, and I have never seen a statement of the conditions essential to its occurrence. These conditions may be briefly stated as follows:—

At any draught of water for which the metacentric curve has a horizontal tangent the principal transverse sections of the surfaces of flotation and buoyancy must be concentric: in other words, the centre of curvature of the curve of flotation must be coincident with the metacentre.

This is very simply proved. Let Fig. 5 represent the cross section of a ship floating at the water-line $W_1 L_1$. For this water-line suppose—

Z = draught of water A C.
V = volume of displacement.
B_1 the centre of buoyancy, at depth y below $W_1 L_1$.
M_1 the transverse metacentre.
I = moment of inertia of plane of flotation, so that $B_1 M_1 = R = \frac{I}{V}$.

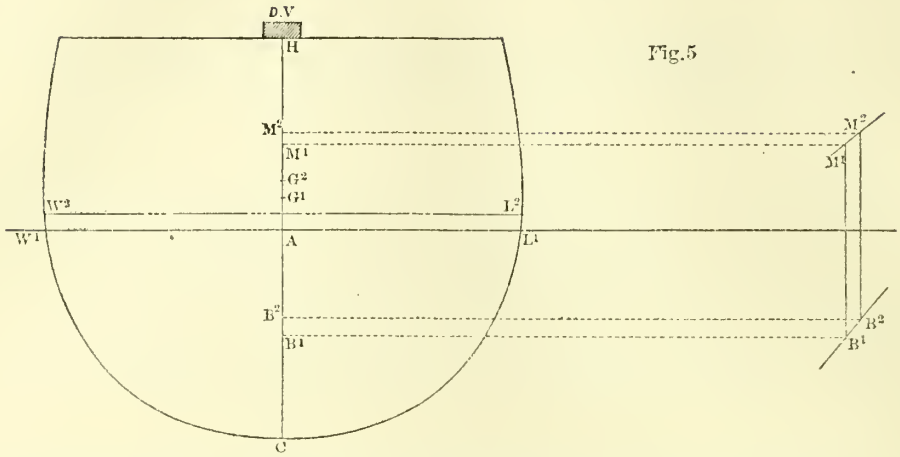


Fig. 5

When the vessel has been immersed to the water-line $W_2\ L_2$, which lies very close to $W_1\ L_1$, suppose—

$Z + dZ$ = draught of water.
$V + dV$ = volume of displacement.
$I + dI$ = moment of inertia of plane of flotation.

The point B_2 indicates the new position of the centre of buoyancy, and M_2 that for the metacentre. Also—

$$B_2 M_2 = R + dR = \frac{I + dI}{V + dV}$$

The following equations will then hold—

(1.) $$dy = B_1 B_2 = \frac{dV\,(y + \frac{1}{2}dz)}{V + dV} = \frac{y \,.\, dV}{V + dV} \text{ (in limit)}$$

(2.) $$dR = B_2 M_2 - B_1 M_1 = \frac{I + dI}{V + dV} - \frac{I}{V} = \frac{V\,dI - I\,dV}{V\,(V + dV)}$$

(3.) $$M_1 M_2 = dy + dR = \frac{y\,dV}{V + dV} + \frac{V\,dI - I\,dV}{V\,(V + dV)} = \frac{V\,dI - dV\,(I - V\,y)}{V\,(V + dV)}$$

(4.) $$(V + dV)\,M_1 M_2 = dI - \frac{I}{V} \,.\, dV + y \,.\, dV.$$

When the tangent to the metacentric curve becomes horizontal, consecutive points upon it such as M_1 and M_2 are at the same height above the line $W_1\ L_1$; in other words $M_1\ M_2 = o$. Equation (3) then becomes—

$$o = V\,dI - dV\,(I - V\,y)$$

whence—

$$\frac{dI}{dV} = \frac{I}{V} - y$$

(5.) . . $$\frac{dI}{dV} = R - y = A\,M_1 \text{ (Fig. 5.)}$$

Now M. Leclert's elegant investigation published in the *Transactions* for 1870, shows that—

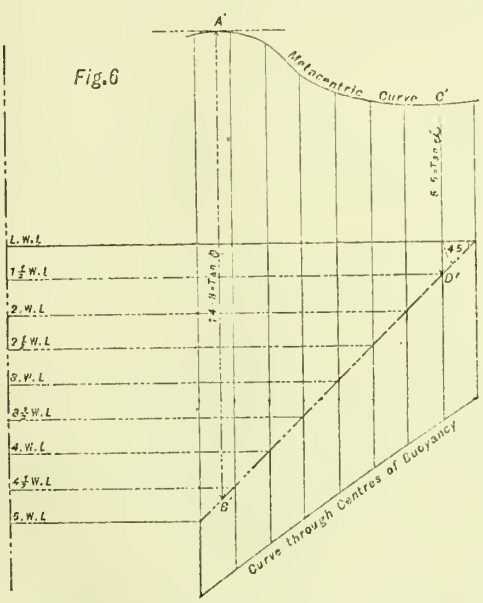
$\frac{dI}{dV}$ = radius of curvature of curve of flotation for water-line $W_1\ L_1$.
$= A\,M_1$

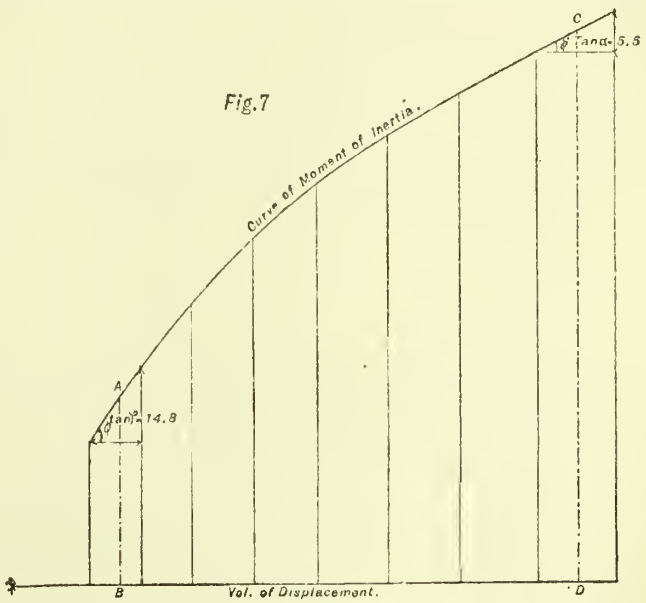
In other words the metaeentre M_1 is eoineident with the eentre of eurvature of the eurve of flotation, when the tangent to the metaeentric eurve beeomes horizontal. (Q. E. D.)

A partieular ease is that for a right eireular eylinder floating with axis horizontal, or for a eigar ship with eircular eross-seetions. Here the centre of the eross-seetions, or the axis of the eylinder, determines the metaeentre for all draughts: henee the metaeentric eurve becomes a horizontal straight line in the diagram. But the centre of eurvature of the eurve of flotation at all draughts is also eoineident with the fixed metaeentre, all eurves of flotation being eireles eoncentrie with the eross-sections of the surfaee of the floating body; and the general principle holds good.

Another particular case is that where a ship is "wall-sided" in the neighbourhood of the water-line ($W_1 L_1$ Fig. 5). The eentre of eurvature then lies in the water-line (d I being zero), and if the metaeentrie eurve has a horizontal tangent at the water-line $W_1 L_1$ the metaeentre must lie on that water-line: in other words $W_1 L_1$ will be the horizontal tangent.

This eondition of horizontality in the tangent may oeeur at several points along a metaeentric eurve. In Fig. 6 a metaeentrie eurve for an aetual ship is shown, with two





such points marked A^1 and C^1. Fig 7 is a companion to the metaeentrie diagram in Fig. 6. Measurements along the axis of abscissæ indieate *volumes of displacement* (V), while the ordinates indicate the corresponding *moments of inertia* (I) of the planes of flotation. Henee the inelinations of the tangent to the eurve of moments of inertia determine values of the ratio $\frac{d\,\mathrm{I}}{d\,\mathrm{V}}$ and of the radii of eurvature of the eurves of flotation at different draughts, in the manner suggested by M. Leelert. To the point A^1 on the metaeentric diagram (Fig. 6) corresponds the ordinate A B on Fig. 7. Henee aeeording to the general prineiple above stated the ratio $\frac{d\,\mathrm{I}}{d\,\mathrm{V}}$ at the point A should be equal

to the height of A^1 above the corresponding water-line: this height is indicated by the length $A^1 B^1$ in Fig 6, and is 14·8 feet, which exactly equals the ratio $\frac{d\,I}{d\,V}$ given by Fig. 7 at the point A. Similarly it will be seen that at the point C in Fig. 7 the ratio $\frac{d\,I}{d\,V} = 5{\cdot}5$ which again is exactly equal to the height $C^1 D^1$ of the metacentre above the corresponding load line, when the tangent (at C^1) to the metacentric curve is horizontal.

Fig.8

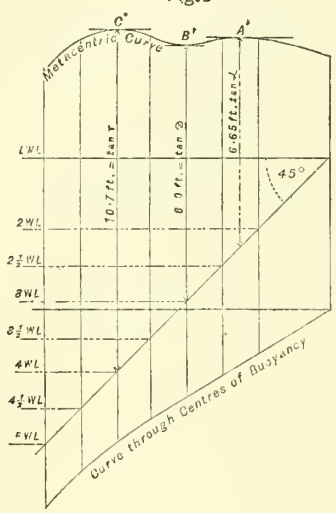
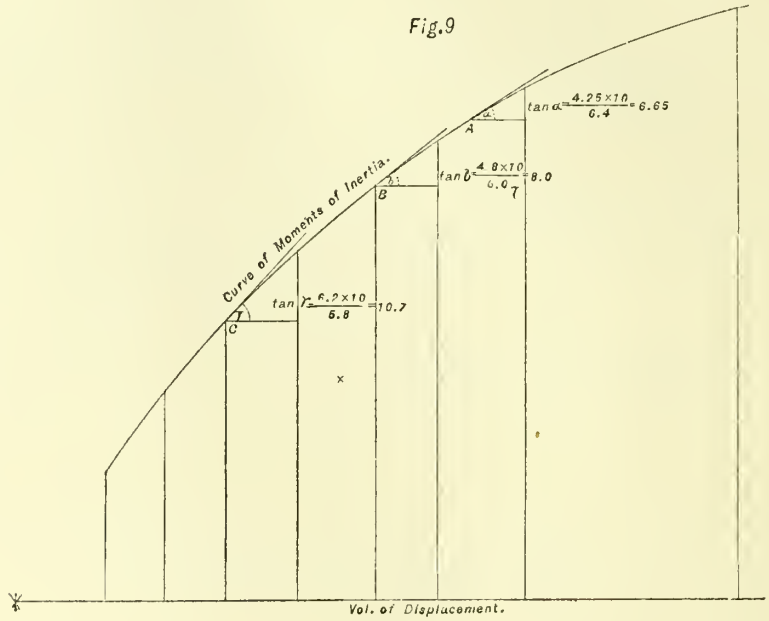


Fig.9



Figs. 8 and 9 illustrate the corresponding conditions for another ship, where the points A^1, B^1, C^1 on Fig. 8, at which the metacentric curve has horizontal tangents, correspond to A, B, and C respectively on Fig. 9. It will be seen that in each case the ratio $\frac{d\,I}{d\,V}$ equals the height of the metacentre above its appropriate water-line, thus agreeing with the general principle stated above.

These diagrams (6—9) have been constructed by two of my pupils amongst the first-year students of the Royal Naval College during the last few weeks, in connection with their instruction in ship calculations. I have other examples confirming the general principle, but it appears unnecessary to give them. It will be obvious that when once the curves of moments of inertia (such as those in Figs. 7 and 9) have been drawn, and the locus of the centre of buoyancy determined, any number of points can be easily obtained on the metacentric curve in order to check its correctness. This is occasionally desirable when the curve presents singularities of form, like those in Fig. 8.

Second: as to the practical application of the preceding equations (page 3) to the estimate of the effect produced upon the *stiffness*—or initial transverse stability—of a ship by adding or removing weights: these weights being supposed to be very small in proportion to the total weight of the ship.

Reverting to Fig. 5, let it be supposed that the additional immersion from $W_1 L_1$ to $W_2 L_2$ has resulted from placing on board at the point H a weight equivalent to the volume d V. Before this weight was added the centre of gravity was at G_1; after it is on board the centre of gravity rises to G_2, and we have (taking moments about G_1)—

$$(6.) \qquad (V + d V)\,\overline{G_1 G_2} = d V \,.\, \overline{G_1 H}.$$

Also—

$$\text{Change in initial stability} = (V + d V)\,\overline{G_2 M_2} - V \,.\, G_1 M_1.$$

Now—

$$G_2 M_2 = G_1 M_1 + M_1 M_2 - G_1 G_2$$
$$\therefore (V + d V)\, G_2 M_2 = (V + d V)\,(G_1 M_1 + M_1 M_2 - G_1 G_2)$$

Whence—

$$(V + d V)\, G_2 M_2 - V \,.\, G_1 M_1 = (V + d V)\, M_1 M_2 + d V \,.\, G_1 M_1 - (V + d V)\, G_1 G_2.$$

Substituting from equation (4), page 3, and from equation (6) this becomes—

$$(V + d V)\, G_2 M_2 - V \,.\, G_1 M_1 = d I - d V \left\{ \frac{I}{V} - y - G_1 M_1 + G_1 H \right\}$$
$$= d I - d V\,(B_1 M_1 - M_1 G_1 + G_1 H - A B_1)$$
$$= d I - d V \,.\, (B_1 H - A B_1)$$
$$\therefore \text{Change in stiffness} = d s = d I - d V \,.\, \overline{A H}$$
$$\frac{d s}{d V} = \frac{d I}{d V} - \overline{A H}$$

Whence it follows that the weights added must be placed at the height of the centre of curvature of the curve of flotation, if their addition is to leave the stiffness unchanged. For in that case—

$$\frac{d I}{d V} - A H = o$$
$$A H = \frac{d I}{d V} = \text{radius of curvature of curve of flotation.}$$

This property may be established independently as follows:—The added buoyancy in the zone between the water-lines, such as $W_1 L_1$ and $W_2 L_2$, Fig. 5, will act vertically upwards through the centre of gravity of that zone. When the vessel is upright (as in Fig. 5) this line of action coincides with the middle line of the section. When she is inclined transversely through a small angle the line of action will pass through the centre of gravity of the inclined plane of flotation consecutive to $W_1 L_1$. These two lines of action, in the limit, intersect at a point which is the centre of curvature of the curve of flotation. And if there is to be no change in stiffness the weights added must be placed at the intersection of the two successive lines of action of the added buoyancy—that is to say, at the centre of curvature of the curve of flotation. Further, the distance from the centre of curvature of the point H, where the centre of gravity of the added weights is situated, determines the change in stiffness.

The common rule for ascertaining the change in stiffness resulting from adding small weights, and which answers exceedingly well in practice, assumes that the water-lines $W_1 L_1$ and $W_2 L_2$ have identical moments of inertia; so that $\frac{d I}{d V} = o$ and the centre of curvature of the curve of flotation lies in the water-line. If $d V$ = weight added, and h is the height of its centre of gravity above the centre of gravity of the

zone of displacement between the water-lines $W_1 L_1$ and $W_2 L_2$, then the ordinary rule gives—

$$\text{Change in stiffness} = d\,V \times h.$$

which becomes zero when $h = o$; this being only a particular case of the general statement given above.

It is worth notice that in very many ships the metacentric curve in the region of the load line is very nearly horizontal; in such cases the height h should be measured from the metacentric curve, and not from the centre of gravity of the zone of displacement, if the expression change of stiffness $= d\,V \times h$ is to hold. This also is a particular case of the general principle.

In practice the most common case is that where the metacentre and centre of curvature of the curve of flotation both lie so close to the load water-line, that no error of importance is involved in measuring the height h for the centre of gravity of the added weights from the load line, in order that the change in stiffness may be expressed in the form $d\,V \times h$.

Mr. Barnes has investigated the general conditions for changes in initial stability produced by adding weights of any amount; and his investigation will be found in *Shipbuilding Theoretical and Practical* (pages 51 to 56). The simple formula eventually obtained by him deserves to be better known; it may be thus expressed—

$$\text{Change in initial stability} \propto \Delta I \pm \Delta V . \bar{x}$$

where ΔI = the difference in the moments of inertia of the original and altered water-lines;

ΔV = increased volume of displacement, corresponding to added weights;

$\bar{x}$ = vertical distance of the centre of gravity of the added weights from the centre of gravity of the volume ΔV.

From curves similar to those in Figs. 7 and 9, the value of ΔI for any value of ΔV can be obtained by a simple measurement; the value of $\bar{x}$ is easily estimated, and so the change in stiffness can be obtained for any addition or removal of weights.

When a metacentric diagram is found to approach horizontality near the load water-line, it may be assumed that the curve of flotation will have its centre of curvature at the metacentre, and this fact may be made use of in drawing the water-lines corresponding to moderate transverse inclinations of the ship.

The principles laid down in this Note for transverse inclinations, of course, hold for longitudinal and "skew" inclinations.

DISCUSSION.

Dr. Joseph Woolley (Vice-President): My Lord, I feel great difficulty in speaking upon this Paper of Mr. White's, for the simple reason that I have no fault to find with it. If there had been any faults to find with it, it would have been easy enough to find words to express them. I believe it is much easier to find fault than to praise; but this much I do say, that I have carefully read through the whole of this Paper, and I thoroughly endorse all that Mr. White has said in it. No doubt he is strictly mathematically correct. I think it is, in fact, an extension of those valuable investigations which were begun some fifty years ago by M. le Baron Dupin, and since continued and illustrated largely by Mr. White and Mr. John in this Institution, and also by M. Leclert, who is one of the Professors of the French School.

I think myself that the application Mr. White speaks of is really more important than he is inclined himself to give it credit for; but it shows this, that there are at least two places in which it is possible to place a small weight without very materially or in any appreciable degree altering the stiffness of the ship. Everybody can see that it may be very important to a sailor, when he finds his ship behaves in all respects with regard to stiffness in the way he desires, not to alter that which he knows to be good, and if it were necessary under any circumstances to introduce a new weight, it would be desirable for him to know, as he may easily do by the application of Mr. Barnes' or Mr. White's Rule, the position in which he should place the weight without altering the qualities of the ship in any degree. My experience has been that wherever we have a true theory some practical application of it is found out ultimately. On that account I am always delighted to find our younger Members striking out these new extensions of principles which have been long established. I think in that point of view we are under very great obligations to Mr. White and other junior Members of this Institution for pursuing, as they have done, the subject in this direction. I was very pleased to hear yesterday from a gentleman who is not present now (Mr. Denny), that there are so many private yards in which applications of this kind can be made without going very deeply into theory. I believe my friend on my right (Mr. Inglis) is one of those people in whose yard that principle has been established. I think Mr. White's Paper has application to that. I also think the Institution is to be congratulated upon the effect of the work which they have been carrying on now for so many years, and upon the announcement made to us to-day.

Mr. John Scott Russell, F.R.S. (Vice-President): I think this Paper an extremely good one, and good chiefly because a subject which generally is a very complicated one is here treated in an extremely luminous manner. In the first place, I am very glad that Mr. White takes as his point of departure for such lines the simple circular section, or cylindrical vessel, because no doubt in the cylindrical vessel a great many problems that appear complicated in other shapes become luminous, and tell their own stories. Taking then a departure from the circular section, and following that departure, his section has the beautiful quality of reducing all these complicated formulæ to the relation of two simple sides of right-angled co-ordinates connected by that curve in a manner which enables any one who has studied thoroughly the geometry of a ship to analyse those very difficult questions in regard to centres of buoyancy, and metacentres, and varying stability, which may be said to be the great bugbear of modern naval construction. I think that diagram of his is a more luminous rendering of the subject than I have seen before.

Mr. William John (Member of Council): My Lord, I should like to say one word, and that is to express my satisfaction at having read this Paper. Mr. White has kindly said that he and I with others of our colleagues have been working at this subject for a considerable time, and I may say that this general solution which has been arrived at is a thing which a good many of us have been nibbling at, if I may use the expression, for some time. We have known that there has been a relation between these curves of buoyancy and flotation, and connected in some way or other with that turning point, the metacentric curve; and I think Mr. White's solution of it is extremely pretty, and as neat a thing as I have seen for a long time in the theory of naval architecture. Now one word about the practical application of those metacentric curves. I find they are enormously useful. They have an important bearing in this way. Take the case of two ships—the case of a ship loaded and a ship light—merchant vessels. A great deal depends on the direction in which that metacentric curve goes as to putting in weights and the question of ballasting. I may perhaps illustrate it in this way. If we have the metacentre *here*, and the centre of gravity in a fixed place *there*, in the loaded condition, the actual metacentric height of the vessel, which is the measure of her stability, would be governed by the relative positions of *those* two points. If the metacentric curve is a horizontal one like *this*, [describing] you will quite see that we have only to look after the one point, namely, how the centre of gravity shifts; and if we know where the centre of gravity is, we can take out weights from the ship or put weights in the ship, and so keep the centre of gravity fixed, because we know we are right as far as our metacentric height is concerned. But if our metacentre comes downward as the ship gets deeper in the water, you may be practically putting in weights and lowering your centre of gravity, and at the same time may be destroying your stability. I have found a vast difference in sailing vessels of about the same tonnage, arising from a difference in the rise of the floor. In some vessels they are very tender indeed when they are light, and when they are loaded with a homogeneous cargo they become stiff. Other vessels are stiff when they are light, but no stiffer than other vessels when they are loaded. All those points turn upon

the direction in which that metacentric curve goes. I will mention one thing more with reference to that curve to show that there are different ways of getting at the same thing. I remember some years ago, I think in the first number of *Naval Science*, in an article which I wrote, I was thinking about this matter, and looking at the question of how *this* metacentric curve altered, and I saw that there must be some point down *here* [describing] where you could take out or put in a weight without affecting the stability. I saw you could trace a curve, not the same curve as *that*, but a curve which gave you the height in the ship at which you could take out or put in weights when you knew the draught of the ship without affecting her stability.

Mr. E. J. Reed, C.B., F.R.S., M.P. (Vice-President): My Lord, I should like to congratulate Mr White on this Paper. Mr. White has been, as probably every one in the room knows, doing very valuable work in the nature of a compilation covering the whole subject of naval architecture, with the view of improving the knowledge and facilitating the acquisition of naval officers. I would venture to say that that work is one of the most valuable that has ever been done. It must be very gratifying indeed to this Institution to find that a gentleman who has been good enough to divert himself from the fascinating pursuit of science of naval architecture to other new developments, in order to give the benefit of books such as he has written, has still found time to extend the principle of the science. I, for one, was rather afraid it might happen that we should lose in some degree Mr. White's labours in the extension of naval architecture, but it is very agreeable to me to find that we are doing nothing of the kind. I think this Paper is more important probably than Mr. White supposes, or rather than he has stated, and I cannot help thinking as I heard him read it, although I have not had the opportunity of perusing it, that the principles embodied in this Paper and brought to light by it, might have had, if they had been known years ago, a very striking application. I cannot help thinking, from what I remember of the *Eurydice*, that if this state of knowledge had existed at the time of her design, it might have had very serious application to her case, because, from what I remember of her, I cannot help thinking she is a vessel in which this depression of the metacentric curve might possibly be found to exist. After the horrors of the loss have passed away, and when we are able to consider the matter in the field of science, and that only, I think it would be a very desirable thing to learn, because I consider that we should not allow great catastrophes like that to happen, and not get from them all the benefit that may arise. It is not a scientific thing, or a desirable thing in many other respects, to dismiss from our minds a great catastrophe like that with the mere statement that a gust of wind blew, or that the ports were open, or that there was some little negligence on the part of the officers. If there is anything in such a catastrophe to throw light upon the science of naval architecture, and to give us caution as to the future, I think we should ascertain it. Although I should be sorry to wish to connect the *Eurydice's* loss with any question of design, I think that in the time to come it would be a very satisfactory thing to know what was her state with reference to this particular question. I cannot help thinking it will be found that she was one of those sailing ships in which this principle, which was not suspected, as Mr. White stated, until quite recently, was found to hold. I do not know whether there is any opportunity at all in the Admiralty for making the calculations, but certainly, if no one else will make them, if I can obtain possession of the *Eurydice's* designs and particulars I should not grudge the bestowal of the work upon it, because I think a great service would be rendered to the public by inquiring into the actual character of the *Eurydice*.

The President: I think after what has passed I may congratulate Mr. White on having, in the opinion of the best possible judges, contributed in this case, as he has in so many others, a very valuable Paper to our *Transactions*, and I beg to thank him in the name of this Meeting.

Mr. William Henry White (Member): I should like to make one or two remarks. First of all, Mr. Scott Russell will know that although I used the cylinder as an illustration it was not my point of departure when arriving at the general law. I always like when I am testing a principle to take it in the simplest form, so as to disclose error if there is any, and I thought the cylinder must show if there was anything wrong in the law stated in the Paper.

Mr. J. Scott Russell: I did not mean that a cylinder was a point.

Mr. White: Mr. John has mentioned a most important fact, to which Dr. Woolley also alluded, namely, that you may by adding weight lose stability, because the metacentre falls more rapidly than the centre of gravity as the draught increases. If gentlemen who have the Paper will kindly turn to Fig. 2, they will see the way in which the metacentric curve there, owing to the peg-top form of the bottom, drops as the ship lightens, which is the direct converse of the common case illustrated by Fig. 1.

I may say, without entering into the question of the causes which contributed to the loss of the *Eurydice*, as a matter of information and interest, that when she was thirty years old the ship was inclined and her metacentric curve calculated, when she was fitted out again as a training-ship: this was done simply as a matter of office information. Her metacentric curve is not nearly so pronounced in its convexity as that of the *Symondite* type illustrated in Fig. 2, her bottom being less "peg-top" in shape. Consequently the metacentre does not fall so rapidly in the ship as she lightens. Now look at Fig. 4, and it will be seen that the metacentric curve dips by a hollow instead of being convex. That is a case which Mr. John's Paper last year on the stability of ships illustrated. In fact, I thought of borrowing his diagrams, but I had others of the same class. It is a case which commonly occurs in deeply-laden merchant ships. I have in vain attempted to get Mr. Inglis to rise to say for himself what he has done, but he has given me the full metacentric diagrams of a sailing-ship which he has built himself and inclined, and it is a most instructive and interesting case. The information which I am glad to say has come to my hands from the private trade adds very much to my own knowledge, and gives me an opportunity of deciding problems which perhaps, from my almost exclusive acquaintance with war ships, I could not in any other way deal with so generally. I am extremely obliged to the gentlemen who have spoken so favourably of the Paper.

ON THE WAVE PRINCIPLE APPLIED TO THE LONGITUDINAL DISPOSITION ON IMMERSED VOLUME.

By Colin Archer, Esq., Laurvig, Norway.

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Recent investigations seem to have made it clear that the direct resistance which a vessel meets with in her progress through the water, may be properly referred to two distinct causes independent of each other, and which may therefore most conveniently be treated separately—namely, Surface Friction and the Formation of Waves.

The latter element of resistance seems of these by far the most subtle question to deal with, and there is not yet, as far as I am aware, any universally-accepted theory on the subject sufficiently comprehensive in character to serve as a guide to the naval architect generally.

It is unnecessary to dwell upon the importance of a question which must have obtruded itself upon everyone who has attempted to construct a fast vessel. Ever since naval construction began to be treated scientifically it seems to have been looked upon as an important object of inquiry. We accordingly find it touched upon more or less explicitly in almost every work on naval architecture with pretentions to anything like completeness, and a variety of theories have been advanced bearing upon the subject. None of these have, however, been able to stand the test of practical experience, or to have been generally adopted.

The remarks offered in this Paper will be confined to a consideration of the wave-making properties of ships, or the resistance due to the formation of waves; and in venturing to bring forward in this place the views to which I have been led on this subject, I am influenced as much by the hope of drawing attention to the real problems involved, as by any belief in the absolute correctness of those views.

In dealing with questions of this nature it is important to discriminate between those features which are essential for arriving at a just conclusion, and those which may with safety be neglected as irrelevant, so that the subject may be divested of all unnecessary complications. A neglect of such discrimination has sometimes led to much vagueness and ambiguity, and has proved a fruitful source of error.

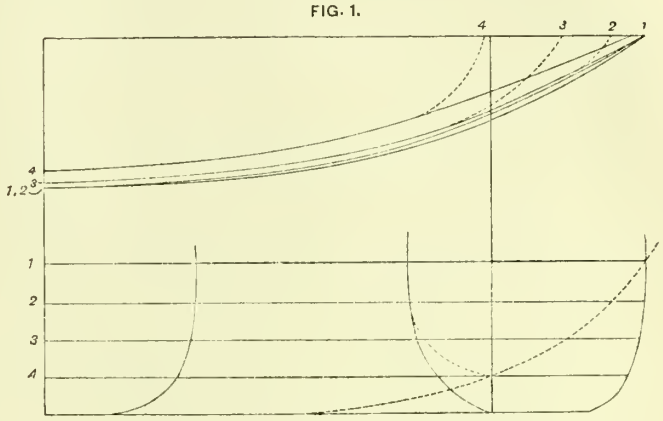
We find not unfrequently systems of construction proposed in which some particular set of lines is selected to be operated upon, applying rules for giving those lines some shape supposed to be superior to any other, and neglecting other lines equally important in the design. Whether the conventional name "*Water*-lines" has led to a belief in the superior efficacy of those lines it is difficult to say, but we certainly find as a general

rule that more attention is paid to those so-called water-lines than to any other set of lines. As an instance, methods have been proposed, and are probably used, for determining the resistance a ship may be expected to meet, based upon the angle which the water-lines of the bow and stern make with the vessel's middle line. Such a test cannot be expected to give trustworthy results if applied to other ships than such as are of a stereotype form, because no provision is made for taking into account other features of a variable nature which are equally important in an analysis of the vessel's form.

It is well known that the water-lines do not correctly represent the manner in which the water is displaced, nor do they indicate the tracks of the water particles along the ship's bottom.

In Fig. 1 the full lines represent the half breadth and sheer plans of a ship's entrance. If the under side of the model is rounded up, as shown by the ticked lines, it is evident that the model after this alteration will have different wave-making properties, and will meet with a resistance different in amount from what the original model would meet. And, if we look to the water-lines only, we might be disposed to infer that this resistance would be much increased in the altered model; for, in the original, these lines are seen all to form easy curves and to meet the middle line at acute angles; whereas in the altered model the water-lines (all but the upper one, which is unchanged) form abrupt curves and strike the middle line at very obtuse angles. Yet, in point of fact, the altered model would be found to displace the water much more easily than the original. Its entrance is sharper, although its water-lines are the reverse. The water lines are, in this case, no criterion of the relative resistance the two models would meet with. And this is true generally when treating of one set of lines, because other features influencing the element under investigation are variable; because some vessels carry a straight floor from fore-foot to heel, while in others no part of the floor is straight; because in vessels of various types the vertical longitudinal sections vary as much in shape as do the horizontal ones, and are as important for determining the resistance.

FIG. 1.



What I wish to establish is this, that an analysis of the curves of any one set of lines, or of the shapes of sections in any one direction, is quite inadequate to convey a correct idea of the resistance vessels of various forms will meet from generating waves; and that, if we endeavour to arrive at a solid form of least resistance by operation upon such lines, we are on the wrong scent. We are at least in so doing adopting a method which is indirect, and, therefore, inconvenient, inasmuch as we are dealing with a feature which bears no fixed relation—though it does bear a relation of a variable nature—to that property or that condition which is the governing one, and, therefore, all-important with reference to the manner in which waves will be generated.

It seems to me that more expanded views on this subject would tend to modify to

a great extent some generally-received conceptions of the properties of lines,—would lead to a more just appreciation of their significance and their value, and even to a radical change of method in treating some of the problems connected with direct resistance. It would be seen that, although a really well-shaped model cannot have really ill-shaped lines, yet a very badly-shaped model may exhibit what are popularly considered very fine lines, and that what are popularly considered very bad lines may belong to a very well-shaped model.

It has been found that water is in a certain sense indifferent to form. If, for instance, a channel has to be excavated in the water it makes no difference whether it be narrow and deep or broad and shallow; whether it be angular, oval, or circular in form. So long as the area of the transverse section of the channel remains the same the work done in excavating a given length is in every case the same.

If we have two vessels of an equal length of fore body and of different sectional shapes, but having at all corresponding points the same area of vertical cross-section, these two fore bodies will when propelled at a given speed be doing precisely the same amount of work and at the same cost. For, not only is the volume of water excavated at any point in the progress of the vessels the same for both, but the *rate* at which it is being excavated is at corresponding stations along the entrances at any instant the same, and, whatever may be the nature of the forces acting or re-acting at such stations on the vessels in consequence of their progress through the water, this action will in each case be the same. I therefore infer that within reasonable limits, and provided all longitudinal lines are continuous and fair, all ships' entrances of the same length, having at all corresponding points the same area of transverse vertical section, have the same wave-making properties.

When a vessel is propelled through the water it is found that the water forced out of her way—or a like quantity—rises above the surface of repose and forms a wave or waves which assume a particular shape. If the vessel's entrance is of an unsuitable shape, and if she is propelled with considerable force, the water is displaced in a form which is not that of a natural wave; and it will then after a time, besides the principal wave of displacement, break up into a series of smaller residuary waves; and these residuary waves may be looked upon as representing the force wasted on account of the entrance having an unsuitable form. We may therefore infer that the most suitable form of entrance is one which displaces the water in such a way that a wave of the natural form will be fully supplied at every stage of its formation, and will at the same time absorb all the water displaced, so that no residuary waves will be thrown off.

In order to fulfil this condition, it is necessary first to ascertain what shape the bow wave of displacement takes, and then to construct the entrance so as to throw off water at a rate sufficient for supplying the wave, and no more. And it is evident that the rate at which water is thrown off is best determined, not by the shape given to any set of lines whatever, but by the *rate of increase in area of the transverse sections.*

As the vessel progresses the channel which the entrance has been excavating, in order to allow the largest section to pass, has again to be closed; and this closing process is effected, not by any force proceeding *directly* from the vessel, but by the action of the water which forms the sides of the channel seeking its own level. The work is done by hydraulic pressure.

When the vessel is propelled at a considerable speed a series of waves is seen to follow in her wake, and these waves are found all to take a form of a certain character

which may be closely represented by a well-known geometrical curve. The inference seems obvious, that the vessel's run should be so shaped as to allow this following wave to be generated in its own way; that the solid vessel should contract sufficiently, but not more than sufficiently, to make room for the water which is being accumulated under her bottom in the process of forming the wave; that the rate at which the solid contracts should correspond at every point with the rate at which the wave naturally grows. And it is needless to say that the rate at which the solid contracts is dependent upon and identical with the rate at which the areas of the transverse sections diminish.

"The wave-line theory" of construction was first brought prominently into notice by the author of the work entitled *The Modern System of Naval Architecture*, and Mr. Scott Russell's name is popularly and deservedly associated with that theory. There probably does not, up to the present time, exist a more complete and elaborate exposition of the wonders of wave phenomena, at the time of its publication comparatively little understood, than we find in that work. Nevertheless, it must be confessed that the working system of naval construction deduced from these phenomena, and elaborated with great ingenuity and skill in the most minute detail, has not succeeded in gaining the confidence of the practical shipbuilder. The eminent author seems not to have succeeded in devising the best means for transferring the wave properties to his solid structures; and, if there is any force in what I have submitted in the early part of this Paper, this want of success may probably be ascribed in a great measure to his having adopted a system of construction by water-lines.

But, whatever may be the defects of the "wave-line system," I am not aware that the accuracy of the observations of wave motion as recorded in the work alluded to has been impugned; and a study of these records, coupled with my own observations on the performances of ships, has led me to adopt Mr. Scott Russell's wave of the first order, or wave of translation, represented by the curve of versed sines, for the bow wave of displacement; and the wave of the second order, or the oscillating sea wave, cycloidal in form, for the wave of replacement aft.

It is said that a wave of the first order has not been observed in open and deep waters, and it is held that it does not and cannot exist there; but I have seen no record of a wave, generated in a manner and under conditions analogous to the primary wave of displacement as generated by the vessel's entrance, having been closely observed at sea and its form accurately ascertained. To do so would, no doubt, be a task of extreme difficulty. The circumstance that the system of waves seen to diverge from the bows of vessels when driven at a great speed, has been found to consist of the ordinary cycloidal oscillating waves, seems scarcely to bear upon the subject. It is evident that the excavating bow wave is essentially different from an oscillating wave, for it has to do that which the latter wave does *not* do. It has permanently to translate the water in the ship's way out of its original place and to deposit it in another place; and this an oscillating wave cannot do. But a wave has been observed, under conditions admitting more readily of observation, which does this. The form it assumes and the manner in which it carries the water from one place into another has been investigated and ascertained, and I assume that this form and this manner is that which the water prefers to adopt in doing the work.

The arguments by which this subject is introduced in the *Modern System*, &c.,

seem also to carry with them much force, and to show that the phenomena of the wave of translation are such as might be looked for, reasoning from known dynamical laws.

But what is of more value than any conclusion of a speculative nature, is the fact that the peculiar form of the wave of the first order is found more or less accurately expressed in the entrances of some of the fastest sailing vessels of their size known. This is more particularly true of American yachts, some of the best of which represent very exactly the curve of versed sines; and, whatever may be the defects of these yachts as powerful sea-going vessels, no one will deny that they possess extraordinary speed.

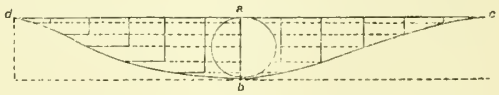
It seems to be established beyond doubt that the refilling wave at the stern is a wave of the cycloidal form, and I conclude that the vessel's run should conform to the "front face" of such a wave. This is actually found to be the case in some of the best yachts of the present day.

It should, however, be observed that this does not imply that the two curves mentioned are conspicuous in the designs of these vessels. In some of those yachts which approach nearest to the wave form there is no trace to be found of a wave-line at any part of the structure.

Assuming these fundamental preliminaries to be settled, the next step is to devise a method, which shall at once be simple in application and effective in its result, for transferring the wave form to a vessel's hull.

The form of transverse section being indifferent, we may choose that most convenient for our present purpose, and the simplest form is the right-angled parallelogram. If we take a straight rectangular piece of wood of a uniform thickness—hereafter to be denoted by the letter t—we may proceed to construct a model out of it. Let the area and station of the largest or midship-section be known. At this station we draw a line ($a\ b$ in the diagram annexed) across the model at right angles to one side, which we may look upon as the middle-line vertical section, and dividing the half area of the midship-section by the thickness (t) we obtain the half breadth of the model at this section. Having reduced our block to this breadth, and striking a circle at the midship-section touching both edges of the block—the cross-line ($a\ b$) drawn as above forming a diameter—we proceed to divide the length of fore body into equal intervals and to construct a curve of versed sines ($b\ c$) from the extreme breadth amidships to the middle line at the forward extremity. We now cut away the model to this curve leaving the curved side vertical as before.

FIG. 2.



Such a model would possess the properties required. It would displace the water so as to give it the form of a wave of translation, and it would translate it out of the ship's way precisely with that degree of gradual acceleration for the first half of the length—where half the excavating work is accomplished—and that gradual retardation for the latter half, which is found to be peculiar to water translated by the natural wave. We have thus a pure wave entrance of a shape not desirable, certainly, to give to a vessel, but of a most convenient shape for taking the areas of the cross-sections at every point; and it is these areas—which are essential—and not the shapes—which are indifferent—we wish to transfer to our vessel.

We may therefore now proceed to design our vessel's entrance, giving her

cross-sections and consequently her longitudinal lines any shape we may on other grounds find desirable, taking care however that every such cross-section has the same area as the corresponding section of our block model.

We have now to consider how we may best secure the desired wave form in the after body; and I conceive that this is best done by constructing a cycloidal curve (*b d*) from the extreme breadth amidships to the middle line at the after extremity, and reducing the model to this curve in the same manner as we have already done in the fore body. That the form of run so obtained would be what is required may appear more evident, if we conceive the model turned over so that the curved side becomes the under side of the model (the diagram thus representing the sheer plan). Since the front of the refilling wave is cycloidal in form it is evident that it would when travelling at the same speed as the ship fill the space vacated by the hull at every point, and would thus at once assume that form which is peculiar to it, no power being wasted in forcing it into some other shape. But, as the refilling water flows with equal facility from all points, the curvature need not be all one way. The body of the vessel may draw in from the bottom, from the sides, and diagonally. The shapes of the cross-sections may in short be such as we on other grounds may find desirable so long as the areas are the same as those found in the cycloidal block model.

These considerations have led me to conclude that a rational application of the wave principle is to treat the wave curves for both entrance and run as the ordinary *curve of areas* of *vertical cross-sections*. The wave curve we have drawn on the model (as shown in the diagram) is evidently this and nothing more.

In proceeding to construct a vessel the first step to take is therefore to construct such a curve securing those properties which we wish our vessel to possess, in so far as her properties are represented by her curve of sections.

But before we can do this with a reasonable prospect of success it will be necessary to consider what those elements are which give to a curve of sections its peculiar character and value, and then to seek for some guide in determining the nature of those elements.

When a vessel is to be designed it is necessary that something about her shall be predetermined. We must have some starting point. I assume that it may be convenient to fix upon the length and the displacement. The length represents to some extent the size of the vessel, and the displacement—or rather the ratio of length to displacement, or the relative weight of the vessel—determines her type, shows whether she is to be of the light, shallow-draught, centre-board type, or a heavy powerful style of vessel. These two elements given, the curve of sections has nothing to do with any of her other dimensions, nor does it indicate the shape of any of her sections, or of her lines. But it shows how her displacement, or the volume immersed, is disposed longitudinally: how much is awarded to the entrance, and what is the rate of increment of volume at every progressive point; how much in the various types is bestowed at or near the middle, and where the largest section is placed; and how much is allotted to the run, and in what manner it tapers off. In order to arrive at trustworthy results in these particulars I have analysed the designs of some of the fastest yachts in England as well as some other good vessels, and from the experience thus gained I have constructed the "Table of Ratios" given hereafter.

The constant nature of the curve adopted for the fore body precludes all discussion as to the fulness to be given to the entrance. The ordinates at corresponding stations

bear in all curves of versed sines the same proportion to the largest ordinate which is the diameter of the construction circle, and the areas of the cross-sections are proportional to these ordinates. Thus, the area of midship-section and the length of fore body being given, the area of any other section and the volume of the fore body are also given.

The area of the wave curve is the same as if a straight line between its extremities were substituted. It is therefore equal to the radius of construction circle multiplied by the length of fore body, or $A_1 = l_1 r$; and the displacement of the fore body is equal to this area multiplied by the thickness of block model, or $d_1 = A_1 t = l_1 r t$.

The next element that claims attention is the area of midship section. This area must necessarily vary in various types in its relation to the vessel's length and to her displacement; and assuming that our best guide in this respect is to be found in practical experience, and that the ratios found to exist in the best vessels of these various types are the best, I have calculated some of these, and the results are given in the columns of the Table headed $L : \sqrt{M}$ and $\sqrt[3]{D} : \sqrt{M}$.

The curve for the after body being cycloidal has not the same constant character as that of the fore body. If we join its extremities by a straight line, the area of the cycloid is found to be equal to the area of the triangle thus produced added to half the area of the circle by which it is constructed; and as the triangle is equal to length of after body times radius of circle, we have area of curve of sections for after body $A_{''} = l_{''} r + \frac{\pi r^2}{2}$, and the displacement of after body, $d_{''} = A_{''} t = l_{''} r t + \frac{\pi r^2 t}{2}$.

The fulness of a vessel's run is a relative expression; it presupposes a standard for comparison. We may here understand by fulness of run the amount of displacement which the run has in excess of what it would have if the line of sections were a straight line, or a curve of versed sines. It is then evident from the above equation that this fulness is directly dependent upon the length of radius used for the construction circle, and this radius thus becomes an important element in determining the shape of this portion of the vessel. As a guide for making a good choice of radius I have calculated its value in good specimens of various types, and the ratios in the Table columns $\sqrt{M} : r$ and $l_{''} : r$, may be looked upon as a mean of those generally found in the best yachts.

The best position for the midship section, or the relative length of fore and after body, is a question on which much diversity of opinion is still seen to prevail. In the work already referred to three-fifths of the whole length for the fore body and two-fifths for the after body is laid down as a "fixed proportion," deduced from wave phenomena. It is not quite clear that the arguments in favour of this proportion apply to sea-going vessels, but as some vessels of a light type, having very nearly this proportion, have shown themselves remarkably fast, it seems at least not improbable that it may be approximately the best proportion for an *ideal* wave model. It is, however, rarely found in any but very light shallow types, and as the length is curtailed—in other words, as the ratio of length to weight decreases—a more forward position for the midship section is found to prevail. The columns in the Table giving ratios of length for the two bodies are based upon such as have been found actually to exist in vessels of similar types.

I now proceed to give the formulæ required for constructing a Wave Curve of Sections, and also for calculating all those elements and properties which a vessel

derives from that curve. The results obtained will be *whole* areas and volumes. It is assumed that the same construction circle is used for both ends.

Let L be whole length of wave curve.
- $l_{'}$ length of curve for fore body.
- $l_{''}$ length of curve for after body.
- A area of whole curve of sections.
- $A_{'}$ area of curve for fore body.
- $A_{''}$ area of curve for after body.
- D whole displacement in cubic feet.
- $d_{'}$ displacement of fore body.
- $d_{''}$ displacement of after body.
- M area of midship-section.
- r radius of construction circle.
- t thickness of block model, or quantity by which an ordinate of the curve of sections must be multiplied to find the area of a vertical cross-section.
- α distance of centre of buoyancy of fore body from midship-section.
- β distance of centre of buoyancy of after body from midship-section.
- γ distance of centre of buoyancy of vessel from midship-section.
- k distance of midship-section from mid-length.
- a distance of centre of buoyancy from mid-length.

We then have—

$$(1.) \qquad A = L r + \frac{\pi r^2}{2},\ A_{'} = l_{'} r,\ A_{''} = l_{''} r + \frac{\pi r^2}{2}.$$

$$D = A t,\ M = 2 r t.$$

From these equations we obtain the following values:—

$$(2.) \qquad D = \frac{2 L M + \pi r M}{4}$$

$$(3.) \qquad M = \frac{2 D}{L + \frac{\pi r}{2}}$$

$$(4.) \qquad L = \frac{2 D}{M} - \frac{\pi r}{2}$$

$$(5.) \qquad r = \frac{4 D}{\pi M} - \frac{2 L}{\pi} = \frac{4 d_{''}}{\pi M} - \frac{2 l_{''}}{\pi}$$

These four last elements—displacement, midship area, length, and radius of construction circle—are those which give to the curve of sections its chief characteristics. Three of these may be fixed upon arbitrarily at the discretion of the designer, the fourth only having to be computed by one of the equations 2, 3, 4, or 5. It is optional which we may choose to begin with; we may take any starting point for our calculations. We also have:—

$$(6.) \qquad t = \frac{D}{A} = \frac{M}{2 r}$$

$$(7.) \qquad a = 0{\cdot}2974\, l_{'}$$

$$(8.) \qquad \beta = \frac{0{\cdot}3927\, r l_{''} + 0{\cdot}31416\, r^2 + 0{\cdot}1487\, l_{''}^2}{0{\cdot}7854\, r + 0{\cdot}5\, l}$$

$$(9.) \qquad \gamma = \frac{A_{,}\alpha - A_{,,}\beta}{A}, \text{ forward, when } A_{,}\alpha > A_{,,}\beta$$

$$= \frac{A_{,,}\beta - A_{,}\alpha}{A}, \text{ aft, when } A_{,,}\beta > A_{,}\alpha$$

$$(10.) \qquad d_{,} = A_{,}t = \frac{l_{,}M}{2}$$

$$(11.) \qquad d_{,,} = A_{,,}t = \frac{2\,l_{,,}M + \pi r M}{4}$$

$$(12.) \qquad k = \frac{l_{,} - l_{,,}}{2}$$

$$(13.) \qquad a = k \mp \gamma$$

These formulæ afford the means of computing all those features which are determinable by a curve of sections. The length of wave curve, position of largest section, and radius of construction circle being given, we may proceed to construct that curve; and it will give us an unerring guide in the work of designing. It does not restrict us to any shape in any of our sections or lines. What is essential is this that every cross-section in our vessel shall have an area equal to the ordinate of the curve at the corresponding station multiplied by the quantity t.

It will be seen that the position of the midship-section, or the relative length of fore and after body, does not affect the equations for the four principal elements above mentioned. That section may therefore be placed at the discretion of the constructor.

Referring to the following Table, it may be necessary to point out that a strict

TABLE OF RATIOS GIVING A GOOD WAVE-CURVE OF SECTIONS FOR SAILING YACHTS.

	Type.	L : $\sqrt[3]{D}$.	L : $\sqrt{M}$.	$\sqrt[3]{D}$: $\sqrt{M}$.	$l_{,}$: $\sqrt{M}$.	$l_{,,}$: $\sqrt{M}$.	$\sqrt{M}$: r.	$l_{,,}$: r.	L = 100. $l_{,}$	L = 100. $l_{,,}$	L : $l_{,,}$
1	Light and Shallow	6·5	12·	1·846	7·	5·	2·69	13·45	58·33	41·66	2·4
2	Light and Shallow	6·25	11·32	1·811	6·51	4·811	2·66	12·828	57·5	42·5	2·35
3	Light to Medium	6·	10·68	1·780	6·09	4·592	2·644	12·138	57·	43·	2·33
4	Light to Medium	5·75	10·04	1·746	5·67	4·367	2·622	11·451	56·5	43·5	2·3
5	Light to Medium	5·5	9·41	1·711	5·27	4·14	2·6	10·765	56·	44·	2·27
6	Powerful Sea-going	5·25	8·8	1·676	4·86	3·94	2·575	10·137	55·25	44·75	2·23
7	Powerful Sea-going	5·	8·2	1·640	4·47	3·73	2·55	9·512	54·5	45·5	2·2
8	Cruisers and Smacks	4·75	7·614	1·603	4·07	3·545	2·525	8·94	53·5	46·5	2·15
9	Cruisers and Smacks	4·5	7·045	1·565	3·67	3·38	2·5	8·454	52·	48·	2·08

adherence to its figures is no part of the system here proposed. As already explained, the ratios given are those found in many good vessels, but as they are found to vary considerably even in such, they are not to be looked upon as determinate quantities. The experienced designer will, on the contrary, find the system sufficiently elastic to enable him to reap every advantage of his experience as well as to experiment in new forms, and he may dispense with the Table altogether and use the formulæ; but to such as lack this experience the proportions given will be found useful as securing a good balance of the various parts.

If the Table is strictly adhered to there will be no necessity for working out the formulæ 2, 3, 4, and 5, since the ratios have already been determined by means of these formulæ. They may, however, be used as checks upon our work and the accuracy of the Table.

The extremities of a wave curve are apparently sharper than a wedge, and such extreme sharpness is not admissible in practice. It will in general be found expedient to cut off from 3 to 4 per cent. of the whole length from the forward extremity, and 4 to 5 per cent. from the after extremity to allow for the thickness of material and for the rudder. The actual extreme length of load water-line will thus be about 8 per cent. shorter than the wave curve.

The vessels to which the method here proposed is more especially applicable are those classes in which speed is a primary consideration. To other classes—for instance, short weight-carrying merchant ships—it will be found less adapted. It is possible, however, that this seeming want of adaptability, which is at first sight calculated to raise a doubt as to the soundness of the principle involved, may be explained by those restrictions which the economy of the ship render imperative, rather than by a defect in the system. Such restrictions are, for instance, a limited draught of water which, in conjunction with a due regard to the principles which influence stiffness and rolling, involve a limited area of midship-section; a compulsory adjustment of the centre of buoyancy; variations of load and trim, &c. The requirements of such vessels will be fully met by adopting a cycloidal curve of sections for both ends, by which means the fulness of the extremities may be regulated to a nicety. In this case, and assuming that the same construction circle is used for both bodies, the fundamental equations become:—

$$A = L r + \pi r^2,\ D = A t,\ M = 2 r t,$$

and formulæ may be derived from these in the same manner as before. Should it be found expedient to use a different circle for each body, or, furthermore, to insert a parallel middle piece, the necessary modifications in these formulæ will readily suggest themselves.

It must be distinctly understood that the method here proposed and the foregoing remarks profess to treat of one of the many questions which must engage the attention of the designer—and one only, namely, the disposition longitudinally of immersed solid with reference to wave-making properties. I have, in order to simplify the subject, studied to avoid every admittance of claims of an impertinent and sometimes of a conflicting nature. Thus I have assumed that the shape of the vertical cross-sections is practically indifferent. But, if this assumption is true as regards wave-making properties, it is certainly most untrue as regards stability, rolling, lateral resistance, and surface friction. Perhaps the most important of all properties in a sailing vessel is her stability, and a defect here cannot be compensated by any amount of care

bestowed in procuring a good curve of sections. It is therefore evident that an adoption of the method I have proposed in no way supersedes the necessity for a study of all those principles which are involved in the science of naval architecture, nor the exercise of every care and precaution which the experienced constructor has at his command for securing a good vessel.

My aim in this Paper has been two-fold. I have, in the first place, endeavoured to divest the question of resistance caused by wave-making of unnecessary complications, by drawing a distinction between such features as have sometimes been treated as of the first importance with reference to that question, but which seem to me to be subordinate, and such as are pertinent to it and essential. And this is a necessary if only an introductory step towards a right understanding of the subject; it at least enables us to bring it within narrower limits than before. We cannot expect successfully to diminish wave resistance until it is quite clear what is the nature of the conditions which produce and regulate it. The question, under this head, to which the practical shipbuilder wants an answer may be stated briefly and comprehensively thus:—Given, any type of vessel—or any proportion of length to weight—what is the best disposition longitudinally, with reference to the formation of waves, of that portion of the vessel which must be immersed in order to carry the weight? This question is, perhaps, too comprehensive to admit of a categorical answer in a few words, but it may be of some advantage even to have it plainly stated.

Secondly, I have explained what seems to me a rational application of the wave principle with reference to the same element of resistance, a transference of wave properties—such as I understand them—to a ship's solid form, by a method easy of application which I have found to work well in practice.

If what I have advanced is found to be true in principle, it cannot fail to influence the point of view from which we have been accustomed to look at the problem of direct resistance, and to lead to important changes, not perhaps in the shapes of vessels—for, after all, these are, as a rule, the result of experience rather than of theory, and experience is still in this point in advance of theory—but in our conceptions of solid form with reference to resistance, and in our method of dealing with the questions bearing upon this subject. Not having seen the point of view here taken up advanced in any work on naval architecture, I assume that it is one which is not generally accepted. We no doubt frequently meet with writers on the subject who lay much stress on the advantages of easy curves in the bow and buttock lines, holding these lines equal and sometimes superior in importance to the water-lines, and who support this opinion by many examples; but, until we find such an opinion referred to a distinct principle which may guide us in choosing a curve for these lines, we must infer that such a principle is wanting, and we are, theoretically, no better off than we were.

We appear to have got into a habit of losing ourselves in admiration of certain graceful curves *in a vessel's design*, imagining that the secret of small resistance must necessarily lie in some such curve; and forgetting that these curves are produced artificially, in an arbitrary manner, without special reference to water-motion, and should be looked upon as useful auxiliaries in the mechanical work of designing rather than as data for estimating resistance.

I submit that no such curve has any special claim to preference; that the longitudinal lines in the design only have significance in so far as they indicate a property which is essential, and which I have called "the rate, longitudinally, of solid

"progression" (increase or decrease of volume); and, further, that this essential property is not determinable by the curves of any one system of lines, but—forasmuch as it must be done by the longitudinal lines—can only be estimated by the correlation of *all* such lines. Collectively and relatively these have much importance, individually and independently they have none.

Looking upon this point of view as established, some important practical results are suggested. For instance, surface friction and the formation of waves being the two chief elements of direct resistance, then, if the rate of progression longitudinally of transverse area, and consequently of volume, is what essentially determines wave-making properties; if a rectangular model, of which the water-line of the entrance is a curve of versed sines and the water-line of the run is a cycloidal curve, has the best rate of solid progression longitudinally with reference to those properties; and if the shape of the vertical cross-sections is practically indifferent with reference to the same properties;—it follows that a half spindle, of which the diametral section is a curve of lines for the fore body, and for the after body a curve bearing the same relation to a curve of sines as the cycloid of the rectangular model bears to a curve of versed sines, is the solid of least direct resistance with reference to the two chief elements above mentioned.

For the sectional areas of such a solid will be found at all points the same as in the rectangular model, and it has thus the best longitudinal form with reference to wave-making. Also, an area cannot be inclosed by a shorter immersed line than the semi-circumference of a circle; and as the cross-sections are all semi-circles, the immersed girth is at all points the smallest possible; consequently, the whole wetted surface—and therefore the surface friction—is the smallest possible.

But it is not my purpose to follow out further this object, however interesting, even in its most obvious consequences. It is one of much importance to the practical naval architect; but the problems to be solved are of such an abstruse nature that their investigation may most probably be classed among those subjects worthy of the experimental philosopher, and to the attention of such it is commended.

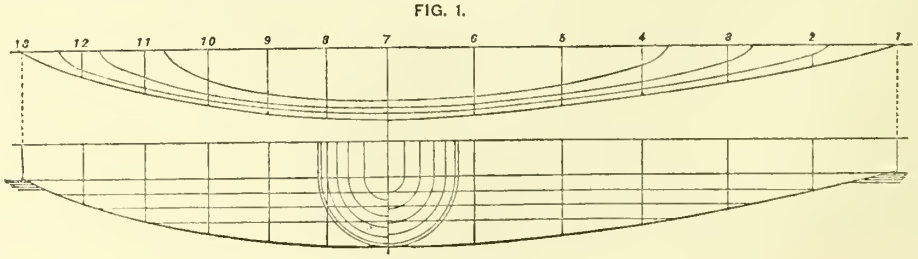
DISCUSSION.

Mr. John Scott Russell, F.R.S. (Vice-President): I dare not allow this Paper to pass without some observations on its ingenuity, its truthfulness, and its accuracy to a great extent. This gentleman is an eminent practical shipbuilder in Norway. He has had great experience in the construction of ships, and very good ships. He appears here in this Paper in two capacities, to which I am bound to pay a little attention. In the one capacity he adopts entirely what he calls Mr. Scott Russell's wave principle—he adopts it wholly and entirely, practically and theoretically. That gratifies me, because it shows me that a practical shipbuilder has found that there are great truths in that principle. He has spent much of his life in applying that principle, and the substance of his Paper is this, that he thinks there are many ways of applying that principle other than the particular way which I afterwards, applying my own principle, adopted as the best mode of carrying it out. That is true to some extent. It is quite true I had a mode of carrying it out which I thought best, which I have generally called the principle of wave lines, which I communicated to all my friends for their use in so far as it could be useful to them; but on the other hand I have always thought that one of the great values of the wave principle was this, that it gave you a principle which, instead of laying down a hard and fast line, enabled you to carry out that principle with perfect freedom according to the particular purposes for which the

ship was to be built; and one of the great beauties, I think, of the wave principle is that it leaves you free to do so, and leaves our friend, Mr. Colin Archer, to carry out the wave principle in any form which is most desirable for his practical purposes. But there is one point which I think may have led him into some misconception, a point in which his valuable Paper might lead you astray upon his weighty authority, and which I am able to put you and him right upon, simply because I myself long ago fell into the same blunder. I believed once that that diagram which we call a solid of revolution—which some philosophers call a parabola, which we now call a spindle form in which all the transverse sections are circles—I thought that that form, as it does, as he says, harmonise with the geometrical displacement of volume which takes place on the wave principle, must be the solid of least resistance. Who could tell without trying it? It has the same law as those wave lines, and who as a practical man can see the least resemblance between Fig. 2 and Fig. 1.* You can see none. There is a hidden and essential resemblance which is purely theoretical, but we will look into that immediately. Then I, in accepting the consequences of the principle, never believed that the wave principle and the wave lines gave the form of least resistance until I tried. I made 120 models. I took *this* exact form as one of the 120; I made the experiments with the greatest precision at a great variety of velocities, and I now give you, what I must give Mr. Colin Archer, the result: though I fancied that it had all these qualities the water did not fancy it, and the water threw it aside, and it made great disturbance in the water, and had far larger resistance than the other. I have nothing more to say. I will explain if you like—only I am afraid time will not admit of much explanation—how that is, and why that is, but I beg to say that geometrically Mr. Colin Archer is right. I say that geometrically I believed when I made these experiments, some fifty years ago I am afraid, that that solid was right, because I thought it was contained in some of the views of Sir Isaac Newton, and some of the views of Sir Isaac Newton are perfectly well expressed in that ship. But I did a great deal more; I made a much larger ship and a steam ship upon the true interpretation of that formula of Sir Isaac Newton's which is comprehended in the diagram, and I found that Newton had made one little mistake. You are aware that in algebraical formulæ a maximum and a minimum have the same expression, and you have to judge whether the result means a maximum or a minimum. I accordingly built a steam ship on Sir Isaac Newton's formula of least resistance, and I found it was only the formula of most resistance, and the ship so constructed was the most difficult of all the 120 to deal with. The algebraical calculation was absolutely perfect, only the water would not have it. How, then, does the water reject, and how does it act upon the body when you put it in the water? I will show you what the water says, and then you can judge for yourselves. Take that spindle form and put it, as I did, on a sheet of smooth water with a semicircular section, never mind what the ship is out of the water. Having taken that shape with its semicircular section and put it in the water, you then begin to draw it through the water. Now allow me to tell you what is the first thing the water does. The water first rebels and does *that* [illustrating]—that is the first thing it does—the water swells up *there*, and merely says, as you know who are familiar with these things, that it is too full *here*. Whenever the water rises up and resists *here*, it says merely that part of the boat is too full in the water-line. The next thing it does—which is fatal, as you will see in a moment—is to kick the bow out of the water altogether, and when you compel the vessel to go ahead whether it will or not it rises and takes a sharp boat out of the water and puts one of these round ships into the water, and that creates a

* The figure No. 1 in Mr. Archer's Paper having been accidentally lost just before the Meetings, and the Author being too far away to communicate with, the accompanying figure, which seemed to suit Mr. Archer's remarks, was put up in the Lecture Room as Fig. 1, and is the one to which Mr. Scott Russell refers; but Mr. Scott Russell states that his observations are equally applicable to the new diagram we have substituted for this one, in the Paper as printed.—Ed.

FIG. 1.



still further rebellion on the part of the water, and then the water does *that* [describing]. That is what the water says to this absolutely perfect mathematical form, which does express, only in another manner, the gradually increasing displacement which is given by a pure wave water-line. If you ask me to explain that, I could very easily, but I am afraid, my Lord, time does not permit. I will end then by merely saying that the only reason such forms cannot be admitted to be wise ways of carrying out the wave principle is that the water will not have them, and perhaps it will be my duty, as Mr. Colin Archer has written such a Paper as this, next year probably, if you choose it, to explain to you why the water does not like it, and why it likes to go another way.

Mr. Dixon Kemp (Associate): I should like to refer to some remarks Mr. Scott Russell has made. Mr. Archer does not mean to say that the spindle model is the best model for speed; what he says is that he designed on the wave theory a boat on a system of areas instead of by water-lines—that is to say, he made each consecutive area represent an ordinate in a curve of versed sines, so that the displacement of the fore body was disposed in a ratio with such a curve, and the displacement of the after body in a ratio with a cycloidal curve.

Mr. J. Scott Russell: I so understood it.

Mr. Dixon Kemp: He does not want circles for the shape of his section. He distinctly says the sections can be made any form the designer chooses. I must explain about the diagram. The original diagram sent was lost, and I selected from some I had the one most suitable to illustrate the Paper, but unfortunately some semi-circular sections were left in which had no business there.

Mr. J. Scott Russell: I think they are quite right.

Mr. Dixon Kemp: It may be so, but it is not the diagram Mr. Archer intended to send to illustrate his Paper.

The President: Although Mr. Colin Archer is not here, I am sure I express the feelings of this Meeting when I say that we are all indebted to him for the Paper which has been read.

ON CRUDE PETROLEUM (GREEK-FIRE) EQUIPMENTS FOR PURPOSES OF NAVAL WARFARE.

By C. Böhm, Esq.

[Read at the Nineteenth Session of the Institution of Naval Architects, 13th April, 1878 ; the Right Hon. Lord Hampton, G.C.B., D.C.L., President, in the Chair.]

If such an authority on laws and customs of war as Admiral Lord Dunsany* pronounces against the use of petroleum in naval warfare, and if a man of his position goes even so far as to advise that "no quarter" should be granted to the crews of ships armed with the petroleum weapon, in order to prevent its general adoption, I must assume also that many of you share his Lordship's feelings, and I think it, therefore, necessary to say a few words why I have taken the liberty to bring before you this apparently unpopular subject.

No enemy will, in my opinion, be deterred from using the petroleum weapon by the threat of "no quarter." On the contrary, this threat will serve him as an encouragement to promote its application, for he will argue that as no other means could be devised to neutralize the effect of petroleum, recourse is being had to the no quarter policy as a *dernier ressort;* and it appears, therefore, to my mind that it would be much wiser to seek for adequate antidotes against the effect of the petroleum weapon than to rely upon a savage mode of warfare, which nails on its flag "no quarter" *in the face of the fact that petroleum is already a recognized agent of warfare.*

It is, probably, a matter of indifference to you whether petroleum was used in naval engagements, under another name, a thousand years ago or more (and I will, therefore, not detain you with an historical retrospect, though you will perhaps allow me to remark, *en passant*, that there is much reason for believing that crude petroleum was the chief ingredient of the Greek-fire, the other ingredients which entered into its composition being merely destined to effect the ignition of the crude petroleum on exposure to atmospheric air). But if we decline, and I think justly and properly, to be influenced in the formation of our opinion as to the use of petroleum in warfare, by the customs and practices of ancient nations, we cannot with equal justice and propriety shut our eyes to, and fail to take into consideration the acts of such great States as Great Britain, France, the United States of America, and Russia.

Well then, Gentlemen, these four highly respectable and powerful States have already used hydro-carbon compounds in warfare during the last twenty-five years, and it is not on record that any Government has protested against it, or that the "no "quarter" policy has been adopted in consequence.

You will find in the *American Encyclopædia* for 1861 that crude petroleum had

* Lecture delivered on the 15th February, 1878, at the Royal United Service Institution.

been introduced into service, under an order from the United States Government, for filling bomb-shells; and from Dr. Russell's "Letters on the Crimean War," as well as in the respective works of the French and Russian Staff "On the Siege of Sebastopol," you will gather that the English have filled bomb-shells with coal-tar naphtha, which they threw into Sebastopol, while the Russians placed wooden cases containing bituminous liquid in the path of unsuspecting English soldiers. And in the French papers of September, 1870, you can read the Proclamation of General Trochu, the then Governor of Paris, dated 10th September, 1870, stating that petroleum would be used in the defence of Paris. On the strength of these historical facts I feel myself justified in assuming that petroleum has been tacitly accepted like gunpowder, dynamite, &c., as a fit compound to destroy life and property for war purposes, although it has been found by experience that the English and American bomb-shells which were filled with hydro-carbon compounds were not so destructive *in proportion to their size* as when filled with other mixtures, and accordingly coal-tar naphtha, and crude petroleum are no longer used in the English and American arsenals for filling bomb-shells, but compounds of far greater destructive power; and if it could be taken for granted that, with ships moving under full steam, out of one hundred large gun shots at least five would hit their mark properly in a naval action, I should not have a *locus standi* to address you on the subject of crude petroleum equipments. But every naval engagement which has been fought during the last twenty years has demonstrated the fact that no reliance can be placed upon artillery fire, and that by its means *you cannot keep the enemy from attacking you at close quarters.* As a consequence of this fact, rams, spar and fish torpedoes have been adopted into service everywhere, and my object is to draw your attention to the circumstance that petroleum equipments could be used with superior advantage in all encounters at close quarters.

The bases of my argument are:—

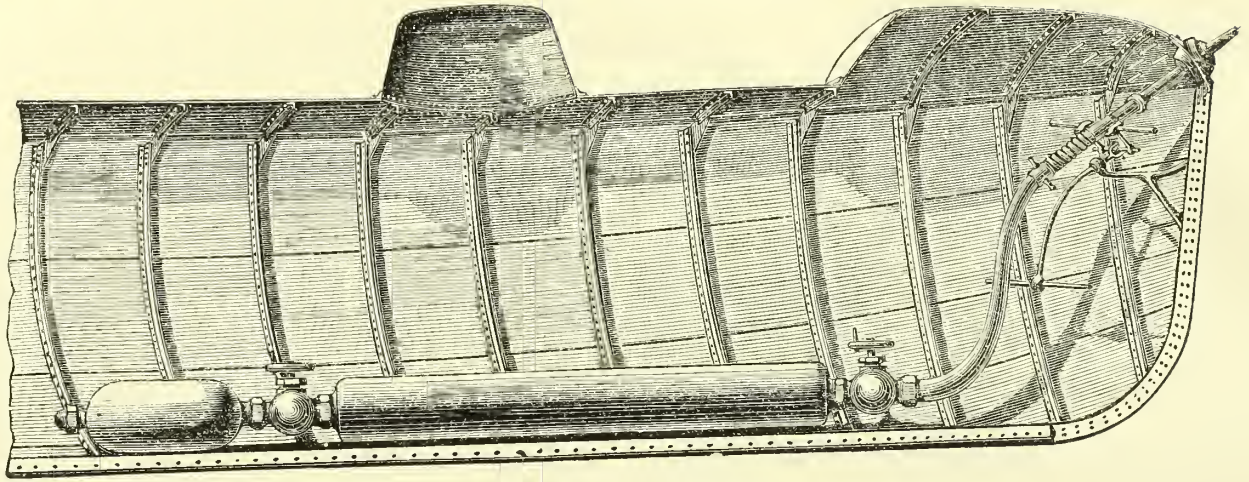
1.—That petroleum can be thrown with accuracy on any desired spot, in any requisite quantity, within 15 seconds, to a distance not exceeding 300 feet; and that 1 gallon of crude petroleum, if judiciously discharged over a surface of 100 square feet and then ignited, will render that area uninhabitable for human beings during ten minutes.

2.—That the Petroleum Apparatus (which I shall presently describe) can be placed on any ironclad or craft and be of any desirable size, as it is intended to serve only as an additional equipment in order that the ship or boat carrying it should be able to retain its original armament and crew, whatever that may be. Thus, for instance, the accompanying diagram shows a Spar Torpedo Boat carrying as an additional equipment the Petroleum Apparatus.

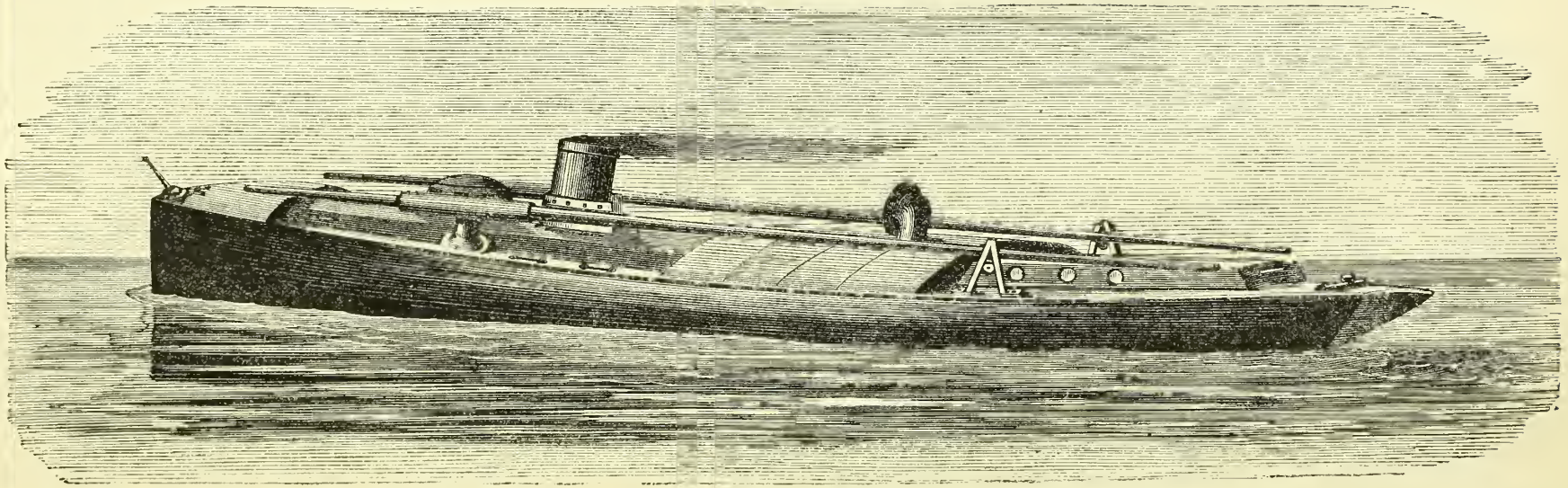
There are various petroleum equipments proposed, but the best known is that of the torpedo boat builders, Messrs. Wigzell, Halsey & Co., of Wandsworth, and the following is the description they give of a 60-gallon apparatus as per diagram.

The apparatus consists of a steel cylinder $\frac{1}{8}$ inch thick, 15 feet long, and 12 inches diameter, affixed to the keel or in any other suitable position in the boat.

A piston is introduced into the bottom end of the cylinder and by a screw-thread or otherwise an iron vessel (the compressed air-chamber) of 2 cubic feet capacity is attached to the cylinder, having previously been filled with compressed air at the air-pump



Section of Bow of Torpedo Boat, showing a Crude Petroleum Equipment.



Wigzell, Halsey & Co's. Spar Torpedo Boat, fitted with a Crude Petroleum Equipment.

(ashore, in the arsenal, or elsewhere) to a pressure of about 500 pounds to the square inch,* and thence carried to the cylinder to be attached as aforesaid. If an air-compressing engine be on board ship for other purposes, or close to the shore, the filling of the air-chamber could be effected by means of a flexible pipe.

The other end of the cylinder is fitted with a coupling joint to receive a discharge pipe of suitable length, diameter and thickness, leading to the deck or superstructure of the boat, where it is fitted by means of a ball-and-socket joint to a delivery-tube of suitable length, having a nozle of $1\frac{3}{4}$ inches internal diameter.

The delivery-tube rests on a stand provided with an arrangement which admits of the nozle being turned in all directions and elevated or depressed, and the whole of it is protected from small fire-arms and Gatling guns by bullet-proof deck and sides, through which at the bow of the boat, where the nozle projects, horizontal apertures are pierced to enable the operator to direct the stream and to effect its ignition.

After the insertion of the piston into the cylinder and the affixing of the air-chamber, the cylinder is first filled with a suitable quantity of water by means of a funnel, which is placed on the nozle. On the water are poured, through the same funnel, 60 gallons of crude petroleum, which will fill the cylinder up to the stop-cock, where the discharge pipe begins. This stop-cock is then closed, and thus it will be seen that the crude petroleum is firmly enclosed in the cylinder, without any chance of leakage or distribution on board ship. The small quantity of petroleum adhering to the discharge pipe, consequent upon the passage of crude petroleum through it during the filling process, is removed by the filling of the discharge pipe with water, whereby all the adhering petroleum is caused to float on the top of the water, and may be removed.

Henceforth the liquid contained in the cylinder may be discharged at any desirable moment by the opening of the respective air and petroleum cocks on the air-chamber, cylinder, and delivery-tube. The compressed air pushes the piston forward, the piston the water in the cylinder, this water the crude petroleum, and the crude petroleum the water in the delivery-tube, which (the water in the delivery-tube) together with the crude petroleum falls on the object aimed at, while the water first introduced in the cylinder would occupy the space in the delivery-tube.

The piston on reaching the other end of the cylinder, would remain there until, after the action, the time for the reloading of the apparatus arrives, and this would be effected as follows, *viz.*:—The compressed air is first allowed to escape from the air-chamber and cylinder, and the air-chamber being removed, the piston is brought by means of the insertion and withdrawal of a rod to its original position, *viz.*, to the end of the cylinder where the chamber is to be screwed on.

By means of the arrangement thus described, the 60 gallons of crude petroleum can be discharged to a distance of about 300 feet in about fifteen seconds on to a hostile ship, where, on its fall, it would most probably be immediately ignited by the discharge of the enemy's own fire-arms, inasmuch as the tiniest spark or flame will set the whole of it on fire at once. But in order not to leave the ignition to this chance, though it may be looked upon almost as a matter of certainty, it is proposed to discharge from a revolver or rifle an incendiary rocket cartridge in the direction of the falling stream of petroleum.

* The pressure will be either smaller or larger, according to the circumstances of the case.

This method of ignition could be replaced, with perfect safety, by setting the liquid on fire as it issues from the nozle; but, as this would obstruct the view of the man directing the stream, it cannot on that account be recommended. The effect of igniting the liquid at the nozle would be simply—a torch in front of the boat until the water reaches the delivery pipe, which takes place in a few seconds, whereas the effect of the 60 gallons of crude petroleum falling and burning on an iron-clad of the largest size now afloat, would render the same for ten to fifteen minutes *hors de combat;* for even if such ship be of such a construction as does not afford food for conflagration, and if, even by the enemy's good luck, the torrent of petroleum fire should not ignite and explode that portion of the enemy's ammunition which may be lying about his batteries in turrets or other spots, and into which the stream of liquid fire would rush and percolate through embrasures and openings, if they are not closed *before* the stream of crude petroleum reaches the ship—and if they are closed the discharge of small arms and cannons must cease—yet, notwithstanding such good luck on the part of the enemy, the attacking Greek-fire torpedo boat will be in a position either to capture or destroy the iron-clad at leisure, by reason of its inability to carry on the defence during the ten or fifteen minutes in which the 60 gallons of crude petroleum are burning. The crew of the iron-clad might, perhaps, if no accidents from explosion of the ammunition happen, and if all openings be closed before the stream of the liquid descends on the ship, abandon its navigation and defence and seek refuge in the hull; and if the superstructure of their ship be of such a nature as will not admit of the conflagration being further fed, the crew might, after ten or fifteen minutes, when the 60 gallons of petroleum have been consumed, emerge from the interior, return on deck and resume the navigation as well as the defence of their iron-clad—provided that the attacking Greek-fire torpedo boat does not know how to utilize the ten or fifteen minutes of utter prostration and complete helplessness of the iron-clad, either to explode at leisure and with ease a torpedo at the most vulnerable and convenient part of the burning iron-clad—or to affix to it in an efficient manner a torpedo and to threaten, on the cessation of the conflagration, to explode the same if the crew refuse to surrender.

Having described to you the crude petroleum equipment and its *modus operandi*, it remains for you to decide whether the case should be met by a "no quarter" policy or rather by an earnest endeavour to discover and to adopt adequate antidotes against the effect of crude petroleum. But, before concluding, allow me to call your attention to the fact that the naval engagements in the late Russo-Turkish War have fully disclosed that large iron-clads must expect to be attacked by small steam launches carried on board of transport steamers and lowered into water when in sight of the enemy; and also that the discharge of a petroleum stream on to the ship about to be attacked would give a better opportunity to apply the spar torpedo, inasmuch as the fire and smoke from the petroleum would drive the men from the guns on board the iron-clad and allow the torpedo boat to approach within striking distance without fear of being fired on; to break away with one spar torpedo the surrounding protections, such as booms, wire nettings, &c., and then to explode the other spar torpedo under the iron-clad itself.

There is reason to believe that in consequence of such considerations, experiments were instituted in Russia with liquid fire, but not earlier than last October, and accordingly too late to put them in practice during the late war. An account of these experiments is given in the St. Petersburg Naval Gazette *Yacht*, of October 22nd, No. 42,

and the conclusion arrived at by the Committee before whom the experiments were tried is to the effect that the liquid fire could be applied with advantage against the enemy's ships, though the apparatus with which the experiments were conducted consisted only of an old fire-engine pump, and was less efficient than the apparatus which I have described.

It may be also worth while mentioning that in Russia they seem to prefer to effect the ignition of the liquid a few feet in front of the nozle, while the stream is in full action, and by means of a spar at one end of which there is a lamp attached. The Russian Committee above referred to have certified that no inconvenience was experienced from the ignition of the liquid a few feet in front of the nozle inasmuch as the onward force of the issuing stream did not allow of the fire rebounding to the nozle.

I imagine that an iron-clad, even of the largest size, and provided with the best armament, would be in a critical position if it be attacked by some eight steam launches carrying spar torpedoes and crude petroleum equipments. Now an iron-clad of that description would cost, everything included, the best part of £1,000,000 sterling, whereas the eight steam launches put together would cost less than £20,000, and if even five out of the eight steam launches were destroyed in the engagement, the remaining three would be quite sufficient to deluge the iron-clad with a torrent of liquid fire, and then either to destroy or to capture the same: thus, arithmetically expressed, £20,000 could be made superior to £1,000,000 in a naval engagement.

The weak points of large iron-clads seem at last to have received due recognition by naval men, since the Russian Government have given contracts for some one hundred and fifty steam torpedo launches, and since, in order to meet the attacks of such small craft, authorities like Lord J. Hay, Lord C. Beresford, Captain Price, &c., instead of trusting to the gun-fire of large iron-clads, have begun to advocate that several torpedo launches should be attached to each iron-clad in the British Navy.* Such torpedo launches must always fight at close quarters, they will therefore constantly either have an opportunity of using the petroleum weapon, or expose themselves to its application by the enemy; it appears accordingly advisable that launches, intended to keep off the torpedo-boat attacks of the enemy by acting as sentinels and skirmishers for large iron-clads, should carry petroleum equipments in addition to their other armament, and be also provided with some precautionary measures against the petroleum weapon, inasmuch as, like iron-clads, steam launches will attack each other, end on, and at full speed, under which conditions, as is well known, no reliance can be placed upon the efficieney of Whitehead torpedoes when discharged from the bows of a ship, and thus though both sides may be armed with them, this weapon will be just as little able to prevent launches from engaging at close quarters as gun-fire was and is able to prevent war ships from hand-to-hand encounters. In such cases then, when the torpedo launches come close together, victory will incline, in my opinion, to that side which is provided with the petroleum equipment; or if both should be possessed of it, *to that side better acquainted with its qualities and uses*. Thus for instance, it may not be essential to await an opportunity to discharge the petroleum directly on to the enemy's torpedo boat, but instead, on the surface of the water, when yet a few hundred yards apart from each other and in the direction of the course of the approaching enemy, who by this manœuvre and wanting the necessary time for the alteration of his course so as to avoid the dangerous path, would suddenly find himself on a lake of fire, and fall an easy prey

* Debate on the Naval Estimates in the House of Commons.

to his antagonist, who, knowing accurately and beforehand the position and expanse of the floating conflagration he was preparing, would keep beyond its reach and take advantage of the enemy's prostration, when emerging from the lake of fire, to destroy or to capture him.

However much we may differ upon other points of this subject, I am sure that you will join me in expressing the hope that petroleum may not be the cause of so much loss of life and property as gunpowder, gun-cotton, dynamite, &c., have already been in warfare.

DISCUSSION.

Admiral SELWYN: My Lord, I desire to speak on this subject, because it happens that I have a very peculiar acquaintance both with the uses and what we may call the abuses of petroleum. At this Institution it is well known I have constantly advocated its use as a form of fuel, and during a long period I have had occasion to use it for destructive purposes. I should wish that the attention of this country should be constantly given to the subject, knowing, as I do, that it will be used, and efficiently used, against us. The question of the attack of an iron-clad by torpedo launches is one that, after all, exists rather in the imagination than in any other way. Torpedo boats have once or twice during the Turkish War succeeded in approaching an iron-clad, but whenever there was a proper look-out kept they came to rapid destruction; because, although some of them were impermeable to rifle fire, they were not impermeable to the Gatling guns carried by the Turkish ships, which pierce easily at 1,000 yards a plate of half an inch thick. The petroleum, however, can do all that the author of the Paper says as regards its rapid ignition, its projection, and its being carried in sufficient quantities to do small work for small ships; but if you come to take a cask of 60 gallons, or double that, and throw that amount of crude petroleum on to an iron-clad's deck, I doubt whether you would produce anything more than a scare. It would be much more formidable to the launch itself if any of it fell into the water around her in flames, because, as we know, the conflagration rapidly spreads over the surface of the water, and the consequence is that the air in the centre of its surface is robbed of its oxygen, and the parties in the boat would die from the absence of oxygen to breathe, and not from the flame itself. Still in large quantities, and employed as contemplated, it is a most formidable element of future warfare. If I have anything to say at all about the Paper itself, or against it, it is as to the concluding sentence. I, on the contrary, hope that destructive agencies will be so far improved as that war will become impossible. That is the only way in which you can get rid of war. When our fleets can only meet together for the destruction of each fleet, we shall cease to send fleets to fight each other. When the policeman is an efficient guardian of the streets, the thief ceases to exercise his calling. But still it is absolutely necessary that we should be as fully acquainted with the subject as any other nation. As to its employment in harbours, I will instance the fact that in, I think, 1867, a barque loaded with 200 tons of crude petroleum took fire in the harbour of Brest. Not only every vessel, but every floating buoy was burnt, and the houses lost the panes of glass on both sides of the harbour at Brest from the explosion.

Mr. C. BÖHM: It was Bordeaux.

Admiral SELWYN: It was in a French harbour. I know it occurred on several occasions when conflagrations of large quantities of petroleum on water have taken place—the effect has been just what the author of the Paper describes, when used for burning bridges, which I have done myself by way of experiment. I have found that it answers admirably for all those purposes; it makes the passage over a bridge impossible during the time the quantity of petroleum is in the water, and it is capable even in sufficient quantities on an iron-clad of proving a very formidable enemy, not so much by the flame, because that does not extend to any sufficient extent at once, but on account of the smoke, which has the effect in crude petroleum of concealing the progress of any small enemy, who might therefore use either

the Whitehead torpedo or some other torpedo better calculated than the spar torpedo to avoid close contact, and thereby destroy the ship. I hope the consequence of this Paper may be that the matter may be fairly studied and thoroughly understood in this country. Mr. Mackintosh ought to receive some acknowledgment, because through his persistently advocating this plan during the Crimean War his patents were seized in order that no use might be made of them. It ought not to be forgotten that we have had early information, if we had only chosen to make ourselves acquainted with the subject.

Mr. MACKINTOSH: My Lord, there is one point in this Paper which I think has not been mentioned, and which is highly important. The colossal fortifications in the Baltic and Black Sea resisted the attacks of the French and English, and in fact Hobart Pasha stated that all the combined iron-clad fleets of Europe could not touch such colossal fortifications. The object of my visit to the Crimea was to mask them—not to destroy them, but to destroy all that they protected. As regards the masking of those fortifications, that requires a very trifling quantity of hydro-carbon. All you have to do is to wait until the wind is favourable and gentle, and sets in the direction of the fortress you wish to mask, you then send in a steam launch with a few puncheons of petroleum. It was tried down at Shoeburyness—not against fortifications, of course. After reaching the fortifications the fuse opens the puncheons or whatever receptacle it is carried in, the stuff comes out, and it is ignited immediately. When that takes place there is an immense smoke, and the wind blows it gently against the fortifications, and the oxygen in the air, which is only 20 per cent., is consumed to support the combustion. Therefore it is carried against the fortifications, goes into the embrasures, and the enemy have no alternative but to retire. We can keep it up for any length of time, and the small vessels, with a long gun, may go close up to the harbour and destroy the ships, and it is not necessary to throw away powder and shot on the fortifications. The next thing that I have to mention is the use of liquid and inflammable shells—shells filled with inflammable material, instead of filling them with water, as Professor Hale used to. The effect of these shells in warfare is most terrible—the bursting charge explodes the shell and scatters its contents with terrible effect. The shower of this inflammable material falling on combustible matter ignites spontaneously and disorganises troops, and in fact destroys everything within its reach. Now, in reference to the question of the use of crude petroleum, I should like to ask the writer of the Paper the difference. Is it a question of economy or efficiency?

Mr. BÖHM: Both efficiency and economy.

Mr. MACKINTOSH: It was found that nothing could be done by filling shells with petroleum—the more highly volatile it was the higher the effect. I have thrown it into casemates for experiment, and the bursting of the shell charged the air in the casemates. Seven of air to one of petroleum makes a highly effective and explosive compound. I do not think you could get that effect with crude petroleum. Whether it is crude or refined does not much matter, but as an element of war I consider it most perfect. Now it is a well-known fact that the peculiarity of this is that it generates an artificial fog, far superior to a natural fog. In the first place, the air is denuded of oxygen, and the Admiral of the ship or fleet can generate that fog when he thinks fit. We know what the Russians did in reference to the fleet at Cefas. The fleet would not come out, and they remained there quietly until nature generated a Black Sea fog for them. Then out they came. They went into Sinope and destroyed what Turkish ships were there, and about 5,000 Turkish troops, without, perhaps, losing a man. Now, only let it be known that we could successfully attack St. Petersburg, Odessa, and Sebastopol, without losing a man, that would place Great Britain in a most efficient position with regard to dictating the peace of Europe. This invention is applicable more particularly to Great Britain, from her being supreme afloat. It seems to me that if the authorities would only adopt it the matter would be almost brought to a close as regards the supremacy of Great Britain, and that supremacy can only be felt by those colossal fortifications in the Baltic being easily masked by the power that is supreme afloat. We can only do it by a power that is master of the position.

The PRESIDENT: Gentlemen, this Paper and this Discussion has, I confess in my mind, only tended to strengthen those feelings which I ventured to express on the first day of this Meeting; and when we find the abilities of scientific men being devoted to the invention of these horrible modes of wholesale destruction of human life, I think the conclusion to which the majority of us will be led is this, rather not so much a feeling that these inventions will add to the horrors of war, as a hope that they may tend to make war altogether impossible.

NOTE.—The following letter has been received from Mr. A. C. Kirk (Member), on the subject of Mr. Böhm's Paper.—*Ed.*

"To the Secretary,
"Institution of Naval Architects.

"24*th April*, 1878.

"SIR,—Not having been present when Mr. Böhm's Paper was read, allow me to add, through you, a few remarks.

"I will not detain you by saying anything on the first part, in which the moral and historical aspects of the use of "petroleum in warfare are treated of, but will at once proceed to the two 'bases' of the author's argument; the first only "need detain us, as if the importance of that is granted, many different ways of carrying it out (which forms the second "basis) can be easily devised.

"I completely dissent from what is stated in the first 'basis'—that one gallon of petroleum judiciously discharged over "a surface of 100 square feet and then ignited will render that area uninhabitable for human beings for ten minutes; and "I do so with some confidence, as I spent six years of my life as Manager of Young's (the largest paraffin oil works in the "country), during which time my experience of such fires was pretty extensive.

"I can corroborate the statement of the author that a jet of petroleum or paraffin oil, if ignited, will carry ignition "with it, and fall as a lighted stream or shower, according to the size of the jet or the distance.

"If this were thrown on sails it would set them on fire, and if thrown on wood it would burn for a short time, but if "thrown on cold iron it would be instantly extinguished, unless the quantity thrown be much greater than contemplated in "the Paper, or than would be practicable from a small boat.

"No doubt if you assume a sufficient number of these craft, in quiet weather, deliberately pouring their jets on an "iron-clad, or a large ship pumping several hundred gallons in a jet like a fire-engine jet, the iron-clad would be rendered "for the time *hors de combat*. But, while one of these small craft might sneak within range, why should an iron-clad allow "a fleet of them or a large vessel to get within reach? Looking to the possibility of such a method of attack being "attempted, it might be well to take certain precautions. The most important of these is that there be no surface of any "extent exposed to the jet, except it be of iron.

"That the present wooden decks be given up and iron ones substituted, as is being now done to a limited extent; and, "of course, that erections on deck, such as flying bridges, companions, &c., be also of iron.

"Some protection for open hatches would be required, perhaps on the plan of Clark's revolving shutters, which could "be quickly drawn over the opening, but at some little distance above the coamings, so as not to stop ventilation. Perhaps "some similar light device might be fitted to be quickly drawn and withdrawn over the gun ports.

"The upper deck might with advantage have more camber with less of a flat in the centre than at present, and be "carried to the side without waterways of any kind, a slit $\frac{1}{2}$ inch or $\frac{3}{4}$ inch wide being left between the deck and the "bulwark to allow any burning petroleum to run off freely. To concentrate it in a stream of fire by collecting it in a "waterway would be a mistake.

"The present hammock-netting would probably be better dispensed with, and the bulwarks of plain plate bent over "inwards for about 3 feet, to form a shelter for men to get under if the fiery spray from a boat's jet was falling on deck.

"Such a shelter would greatly tend to reduce the demoralizing effect of such a shower.

"Extensive experience has proved that the best material for extinguishing petroleum blazing over a surface is sand, "and the next best ashes; the latter of which, at least, is available on board a steam ship.

"To apply water is generally a mistake. If there is any body of hot burning oil, the water converted into steam not "only throws up the oil in spray, but assists the oil to vaporise at a temperature below that at which it would do so "naturally, causing a large quantity of petroleum vapour to be suddenly liberated, burning with a most intense power. "We must remember that before any of these oils can burn they must be first vapourised, then mixed with a due proportion "of air, but if mixed with an excess of air the vapour is harmless.

"There is much popular error on the subject of petroleum explosion, and the mere talk of using it in warfare may "act as a scare and have a demoralising effect, but I trust I have said enough to show that it may be over-estimated. and "by a few simple arrangements met."

ON AN EASY AND EFFECTIVE METHOD OF ASCERTAINING THE RUDDER POWER OF STEAM SHIPS.

By Robert Clark, Esq., Imperial College of Engineering, Tokia, Japan.

[Read at the Nineteenth Session of the Institution of Naval Architects, 13th April, 1878; the Right Hon. Lord Hampton, G.C.B., D.C.L., President, in the Chair.]

Steam ships after being equipped are usually subjected to certain trials to ascertain the diameter of the smallest circle in which they will turn round with the rudder in any given position. These experiments are carried on by means of certain battens and straight edges being brought into line with some object previously thrown overboard in the wake of a vessel. This system of experiment is open to several objections which I shall endeavour to point out.

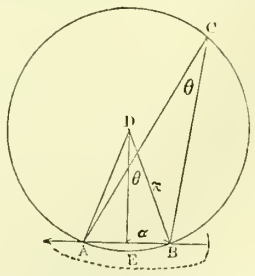
First.—By means of a batten an angle cannot be measured with accuracy, and should the error in the observation amount to not more than a degree, the error in the diameter of the circle would be very material.

Second.—In taking sights by means of battens at least two men are required, and the vessel being in motion error is liable to be engendered by the sights not being entirely simultaneous.

Third.—The buoy or floating object is liable to move from its first position in the wake of the vessel.

These objections may be obviated by pulling a boat into and retaining it in the wake of the ship, and from the boat observing with a sextant the angle subtended at the eye by the two extreme masts of the vessel. This angle as shown in the annexed sketch is constant, and sufficient time is afforded for making the observation with accuracy.

The foregoing observation having been made, at a certain preconcerted signal the angle of the rudder may be changed, and a fresh observation made from the boat, which may be repeated as often as may be deemed necessary. The diameters of the different circles can then be easily calculated from the data at hand; for representing the length between the extreme masts by $2\,a$, and denoting the radius of the required circle by x, we have sin of one of the angles just obtained equal to $\frac{a}{x}$ (x being the radius of the circle the ship described, from which was taken the corresponding angle).



Suppose A and B (*see* diagram) to be the two masts of a ship passing round a circle A B C, we can reasonably assume the straight line A B to be a chord of the

circle A B C; hence the angle subtended at C is constant and equal to the angle E D B, which we denote by θ, and $\sin \theta = \frac{\text{E B}}{\text{B D}} = \frac{a}{x}$; whence $x = \frac{a}{\sin \theta}$, *i.e.*, we have the radius of the required circle expressed in terms of the known distance between the masts and the known angle. For example, take E B = 50 feet, and suppose $\theta = 5°$; then $x = \frac{50}{\sin 5°} = \frac{50}{\cdot 0871557} = 579 \cdot 42$ feet, and supposing the rudder to be altered so that the angle subtended at C or θ shall be 5°, 1′, then as before $x = \frac{50}{\sin 5°, 1'} = \frac{50}{\cdot 0874455} =$ 571·78 feet. Thus a difference of 1 minute, which is easily distinguishable with a sextant, makes the difference between the diameters of these two circles = 15·28 feet, which is certainly considerable.

ON DEPTH AS A FACTOR IN THE COMPUTATION OF YACHT TONNAGE.

By Dixon Kemp, Esq., Associate.

[Read at the Nineteenth Session of the Institution of Naval Architects, 13th April, 1878; the Right Hon. Lord Hampton, G.C.B., D.C.L., President, in the Chair.]

Hitherto the chief of the many difficulties in the way of bringing about an alteration in the Rule of yacht measurement has been the conflicting influences of the various yacht clubs; but now that those yachtsmen who are known as racing men have established an Association for the framing of Sailing Rules, and the measurement of yachts, this difficulty at least has been removed. The Members of the Yacht Racing Association adopted the "Thames Rule" of measurement, but they are in no way pledged to it further than that they are not likely to do anything which would much unsettle existing classes or interfere with present interests.

The measurement formula known as the "Thames Rule" was founded on builders' measurement, by which yachts are still bought and paid for. According to builders' measurement length is taken along the keel from the sternpost to a perpendicular or plumb line dropped from the stem-head on deck. By raking the stern-post the length of keel was shortened, and in order to prevent evasions in this way the Royal London Yacht Club in 1854 passed a Rule that the length should be taken on deck instead of along the keel. The tonnage of the vessels with very raking stern-posts was, of course, much increased, and in order to let them off a little more easily the whole beam was ordered to be subtracted from the length instead of $\frac{3}{5}$ths of the beam. The Rule then read $\frac{(\text{Length} - \text{Breadth}) \times \left(\frac{\text{Breadth}^2}{2}\right)}{94}$. This is the Rule now known as the "Thames Rule," and is the Rule adopted by the Yacht Racing Association. The Thames Rule fairly estimates the value of yachts that are not of very extreme types, for competitive sailing, as it is a rough expression of their sail-carrying power, all yachts built under it being practically proportional in depth, and having a similar disposition of their weights.

The objections to the Rule are:—(1.) That in consequence of the value for competitive sailing being made dependent on beam and length, to the total exclusion of depth, an inducement exists to attempt a possible evasion of the Rule by decreasing beam and compensating for it by an increase of depth. (2.) That the effect of the Rule is to produce one type of vessel—that is a narrow and deep one.

With regard to the first objection it is generally answered by pointing out the advantage already claimed for the Rule, that it fairly expresses the value of a yacht for competitive sailing. The fact is, that the value of breadth as compared with depth is as three to two, and as depth in large vessels is limited by considerations quite as patent as those of sail-carrying power, no successful attempt to evade the just

operation of the Rule by substituting untaxed depth to taxed breadth has yet been recorded.

The second objection that the effect of the Rule is to produce one type of vessel is more or less true, but the answer is readily made that this type is the best possible for sea-going qualities if not quite what it ought to be, under favourable conditions, for developing great speed—these conditions being a strong wind and smooth water. Assuming that the Rule only fairly taxes beam, there must be a strong reason existing for not more largely making use of it in proportion to length; and the conclusion is that for sea-going qualities better results are achieved with a certain limited proportion of beam and a proper allowance of depth.

But that the Rule does tend to produce a narrow and deep type of vessel is sufficiently proved by the fact that no one endeavours to evade the effects of its application by building an excessively broad yacht; but many do attempt the evasion by building exceedingly narrow ones. It cannot be said that these narrow yachts are positively bad sea boats, but they might be better with a little more beam, and their speed performance in smooth water would be undeniably improved by an addition in this respect. But the assumed penalty imposed by the Thames Rule prevents experiments in the way of increasing beam, and encourages those for decreasing it.

But it is not only the operation of the Rule in match sailing that has a tendency to produce the narrow and deep vessel, the tendency is just as much induced by the effect of the Rule as a builder's estimate of the price of a yacht. Every one knows that more accommodation below can be had by increasing length and depth than by increasing beam, and as the relative effect of beam and length on tonnage is as eight to one (that is to say, beam increases tonnage eight times as rapidly as length), it is not surprising that builders are induced to construct long and comparatively narrow vessels. The owners, it is true, have not been the entire gainers in this respect, as the prices have increased with the increase of length, and a yacht now costs 100 per cent. per ton more than she did twenty years ago. This enormous increase is to some extent attributable to the increase in the price of material and labour, but it is mainly owing to the decrease in the proportion of beam to length. Practically, a vessel 80 feet long and 18 feet broad has the same internal accommodation of one 80 feet long and 17 feet broad, and would cost the builder the same to construct; but the latter would by the present rule of measurement be 9 tons smaller, representing about £350.

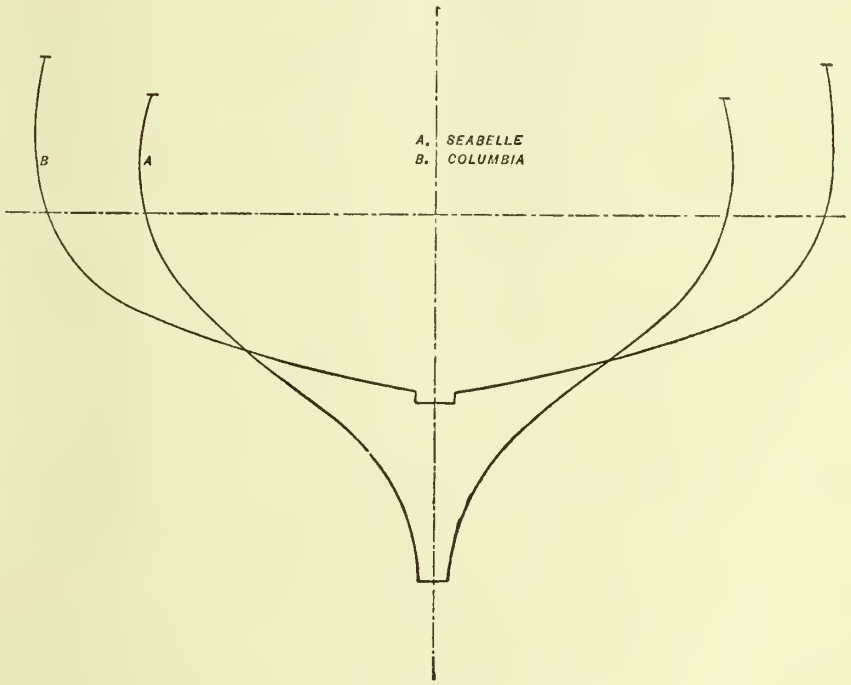
The penalty put upon beam, and the absence of any restriction upon depth or ballasting, have thus forced the naval architect to almost wholly direct his ingenuity to the question of stability, as dependent upon comparative depth and upon ballasting, and he appears therefrom to be unable to largely profit by the results of recent investigations of the laws of the resistance. And the yacht owner is restrained from making any experiments in the way of beam on account of its extreme costliness as compared with the cost of an increase to length.

Rightly or wrongly this is the result of the Thames Rule, and we are asked to provide a Rule that will so equally balance the value of depth and breadth that there shall be no inducement to build a very narrow yacht any more than a very broad one.

The Rule most generally brought forward as fit to displace the Thames Rule is that of displacement; and it is justly argued that if, with a given weight, one man can produce a better vessel for competitive sailing than another, it is only right that he should be able to do so without restriction. But before this proposition is unconditionally

subscribed to it will be well to consider what the effect of a displacement test would be. In the first place, the tendency of the Rule would be to produce broad and very shallow boats, as the displacement must be as small as possible, and the broader the boat the smaller the displacement could be made, and the greater could be the sail area in proportion to the displacement. The other objection to the Rule is that it would utterly fail to class existing yachts of different types, or even variations of the same types.

Both objections can be illustrated by the American yacht *Columbia*, built to compete under a Rule of displacement, and the English yacht *Sea Belle*, built under the Thames Rule. Each yacht is representative of the national type, and each is as good of that type as yet produced. The linear dimensions of the *Columbia* are 98 feet length on the load line, 25 feet 10 inches beam, and a mean draught of 5 feet 10 inches; her displacement is 150 tons, ballast 35 tons, and the lower sail area 7,642 square feet. The *Sea Belle* is 90 feet 6 inches on the load line, 19 feet beam, mean draught 11 feet, displacement 157 tons, ballast 73 tons, and lower sail area 5,780 square feet. The area of the mid-section in each is practically the same, about 102 square feet. Upon reference to the diagram it will be seen that what is cut away from the *Columbia's* mid-section at



the load line has been added to the *Sea Belle* near the keel, and the compensation has been so equally arranged throughout that the displacements of the two vessels are nearly identical. Now the effect of the difference in the disposition of the displacement is, that the *Columbia* carries 32 per cent. more canvas in her lower sail than the *Sea Belle*, and 100 per cent. less ballast. The highest speed attained by the *Columbia* under lower canvas, in a strong breeze and smooth water, was at the rate of $12\frac{1}{2}$ knots per hour. The highest speed attained by the *Sea Belle*, under similar conditions, was $11\frac{1}{4}$ miles per

hour; and the difference in the speed is fairly accountable to the difference in sail area, assuming the resistance at 12 knots to be increasing as the fourth power of the speed.

If these two yachts set out to sail a course of 50 miles with strong and fair wind, the *Columbia* would accomplish the distance in four hours, and the *Sea Belle* in four hours twenty-three minutes. Here are two yachts of nearly the same displacement, and one by adding 36 per cent. to her beam and only 8 per cent. to her length is able to carry 32 per cent. more canvas and attain 10 per cent. greater speed. This would be the inevitable result of attempting to class vessels built under such opposite influences as that of the Thames Rule of dimensions and the American Rule of displacement; but, oddly enough, the Thames Rule will fairly class these two vessels as under it. By the Y. R. A. scale the *Sea Belle* would get sixteen minutes' time allowance for a course of 50 miles, which would perhaps fairly bring the vessels together; but it cannot be said that it would be judicious or fair to class a vessel of the *Columbia's* form by the Thames Rule, which would make her 260 tons. Actually she has only the sail area of an English schooner of 200 tons, and it would be manifestly fairer if a Rule could be made to class the vessels more in constant proportion to their sail areas. The objection to the American Rule of displacement, that it would fail to class existing yachts, would be sufficient to cause its rejection by English clubs; but the more general objection to it would be that it would produce broad and shallow and unseaworthy yachts, expensive to work and deficient in accommodation. The internal accommodation of the *Columbia* is about equal to that of the *Sea Belle*, but the expense of working her would be (in England) about 40 per cent. greater. The great initial stability of the *Columbia*, which enables her to carry her enormous area of canvas well in smooth water, might in unskilful hands be the cause of her capsizing, as she reaches her maximum stability at an inclination of about 30 degrees, and her stability vanishes altogether before she gets to 90 degrees; whereas the *Sea Belle* has more stability at 90 degrees than she has at 30, and is absolutely uncapsizable. These deficiencies are quite sufficient to horrify any English yachtsman, and a Rule that would be calculated to produce them is unlikely to be adopted. It has been suggested that the building of very shallow yachts could be checked by having a limiting co-efficient of displacement; but this would not meet the case, as can be sufficiently proved by the fact that the *Columbia* has a higher co-efficient than the *Sea Belle*, the proportion being ·38 to ·32.

A Rule has been proposed, and indeed used, based on the product of L × B × D. This Rule would fairly class existing English yachts, but it would let in beamy yachts too cheaply, and its tendency inevitably would be to produce shallow vessels; breadth, as before stated, being more valuable for competitive sailing than depth.

Further, it may be taken for granted that no new Rule would be adopted that would much disturb the present classification of yachts (by classification is meant the arrangement of yachts in classes of 5, 10, 15, 20, and 40 tons), and that would place no restriction on the beam which is so valuable for sail-carrying power as against depth, which is of much importance for safety and good sea-going qualities.

Depth is a valuable quality in a yacht, and should be carefully protected, but as it is of less value than beam for competitive sailing, it should not be taxed as if of equal value, or it will be cut away in order that a greater quantity of the more valuable beam may be taken. For good sea-going qualities depth is of equal or more than equal value with beam, and therefore any new Rule should provide for preserving a good proportion of depth.

Depth is understood to mean the distance from the deck to the keel, but if depth were included in any Rule, the height of the bulwarks would have to be considered, as otherwise "water-tight bulwarks" would be made do duty for freeboard.

The mean depth of English yachts, measured from the top rail to the underside of the keel, varies very nearly as the $\sqrt[3]{\left(\frac{L \times B \times D}{35}\right)}$, and the cube root of that product is pretty regularly equal to the actual half beam of English yachts, which half beam is the second multiplicand of the present Y. R. A. Rule which was founded on the Thames Rule.

It will be admitted that existing yachts have a good proportion of depth to other fixed quantities, and if this proportion to any other fixed quantity can be maintained, a little licence may be permitted in the matter of beam. The surest way of having that proportion of depth maintained is to assume that the proportion does actually exist; then if it does not exist it will be the fault of the designer, and he will be careful to get value for the deficiency. It would not do to make the standard value for depth proportional to the beam, or the beam would be cut down and narrow vessels would result; if made proportional to length, that dimension would be shortened and broad shallow vessels would be the result; but if the standard value for depth be made proportional to the product of length × breadth × depth, there will be no particular inducement to increase or decrease any one dimension more than another, so far as the direct operation of a Rule in which such depth is included is concerned.

It has already been stated that the cube root of the product of L × B × D equals the half beam of yachts of the English type; and therefore if the length be multiplied by the breadth and the product by the cube root of the product L × B × D (which as before stated is pretty constantly equal to the half beam of the Thames Rule), it is easy to see that the tonnages of existing yachts need not be altered.

If the depth were reduced the product L × B × D would be smaller, but the cube root will indicate what the proportion of depth should be to that product, and hence practically what the depth should be for any actual displacement; if depth were cut away, because it is taxed in this way, it would be found that the penalty placed upon it could not be avoided altogether.

On the other hand if increased depth is given beyond the proportion indicated the whole increase would not be taxed.

The penalty put on beam would be divided in certain proportions with the penalty proposed to be put on depth.

The Rule formulated would read:—

$$\frac{\sqrt[3]{\left(\frac{L \times B \times D}{35}\right)} \times (L \times B)}{122}$$

or

$$A = \sqrt[3]{\left(\frac{L \times B \times D}{35}\right)}$$

$$P = (L \times B)$$

$$\text{Tonnage} = \frac{(A \times P)}{122}$$

The constant divisor 122 is merely introduced as a substitute for the 94 of the Thames Rule, and would perhaps in practice require alteration in order that the

tonnage value may be expressed in the numbers of the Thames Rule. The exact manner of taking mean depth is also a detail that could be settled hereafter.

Operation of the Rule.

If a man gives his yacht a foot more depth (keeping the other two dimensions of length and breadth unaltered) it is only fair to assume that he does so for some advantage, and penalty should be put upon this depth approaching its value. The Thames Rule takes no cognizance whatsoever of such increase of depth, but by the proposed Rule a certain limited value will be put upon depth, as nearly as possible agreeing with its value in its relation to the value of beam. Thus in a vessel of about 100 tons a foot additional depth will give an increase of 2 tons, whereas a foot more beam will give 7 additional tons. By the Thames Rule no account would be taken of the increase in the depth, but 10 tons would be added for the increase in beam.

But there may be reasons apart from those of match sailing why a foot of depth should be taken off a vessel and not added, but the owner would think twice before doing it, because he would be rated the same by the Thames Rule in competitive sailing, and would have to pay the same for the vessel as if the depth were present. By the proposed Rule the tonnage would be decreased 3 tons.

A reduction in the breadth is usually accompanied by an increase in the depth, but the Thames Rule only accounts for the reduction in the breadth. Upon reference to the Table given further on it will be found that in a vessel of 100 tons a foot less beam and a foot more depth gives a decrease of 6 tons against a decrease of 10 tons under the Thames Rule.

Similarly a decrease in depth is usually accompanied by an increase of beam. By the proposed Rule a foot more beam and a foot less depth will give 5 additional tons against 10 tons by the Thames Rule.

The decrease in the tonnage due to the abstraction of a foot of breadth under the Thames Rule will only be accomplished by reducing the depth 1 foot as well; and as this cutting the stick at both ends would seriously interfere with the sailing qualities of the vessel, it is unlikely that any evasion of its operation would be attempted in that way.

The following Table shows the effect of the Rule on a vessel of about 100 tons, with variations in her depth and breadth.

Length 80 ft.; Breadth 18 ft.; Depth 16 ft.	Proposed Rule.		Y.R.A. Rule.	
	Increase.	Decrease.	Increase.	Decrease.
	Tons.	Tons.	Tons.	Tons.
Foot more depth	2	—	0	—
Foot less depth	—	3	—	0
Foot more beam	7	—	10	—
Foot less beam	—	8	—	10
Foot less beam and foot more depth	—	6	—	10
Foot more beam and foot less depth	5	—	10	—
Foot less beam and foot less depth	—	10	—	10
Foot more beam and more depth	9	—	10	—

The effect of the Rule on existing yachts of 40 tons and under will be that their present relative sizes will be maintained, and they need not be remeasured unless they were altered in length, breadth, or depth after the Rule became law.

By referring to the Table at the end it will be found that the tonnages of the yachts built to compete under the Y. R. A. Rule of measurement, practically remains unaltered, although they are of such widely different proportions as the *Florinda* and the *Jullanàr*.

The *Columbia* has no fixed keel, such as an English yacht has, but she is fitted instead with a centre board; this centre board when down in area is about equal to a foot of depth running her whole length, and it would be strictly fair to include the centre board in the mean depth of such a vessel.

	Length.	Breadth.	Depth.	Displacement	Y.R.A. Tons.	Proposed Rule Tons.	Sail Area.
							sq. ft.
Sappho	124	27	17·5	232	376	326	10,223
Guinevere	124	23·5	19	297	294	279	8,611
Aline	105	22	16·8	190	215	197	6,710
Columbia	99	25·8	14·3	150	260	204	7,642
Including centre board ...	99	25·8	15·3	150	260	210	7,642
Gwendolin	105	21	18·5	202	197	190	7,350
Sea Belle	92	19	18	157	140	140	5,780
Jullanàr	100	16·9	16·5	160	127	128	5,000
Florinda	88·5	19·3	17	148	138	132	5,260
Kriemhilda	82·1	17·5	16	115	106	103	4,405
Bloodhound	61·6	12·3	12·8	47	40	40	2,600
Christine	67·3	11·5	14·6	...	40	43	2,700
Vanessa	48·3	9·8	11	28·5	20	20	1,730
Lily	37·8	8·1	9·2	13	11	11	1,095

DISCUSSION.

Mr. William Henry White (Member of Council): I wish to ask one or two questions, because this is a matter on which Mr. Kemp has already given me much information, and I hope will give me more. I should like to know first of all exactly where the length is measured in this Rule, and secondly what would be taken as the depth in a vessel like the *Columbia*, with a sliding keel? Further, with reference to the statement made that the *Columbia* might be more dangerous than the *Sea Belle*, I should like to know what are the relative or probable angles of steady heel with plain sail set for each yacht? because, though we have a statement as to the range of stability and the angle of maximum stability, yet I should guess the *Columbia* would have a much less angle of steady heel, and of course that is an important element in the question of safety. The great merit which Mr. Kemp's proposed Rule has from his point of view seems to be this—it leaves the tonnage the same as the present Rule—the Thames Yacht measurement which he admires as producing a good sea-going type of yacht. I am not a yachtsman, but I have endeavoured to get at the bottom of the tonnage measurement which is so much admired by all practical yachtsmen; and to understand why this Rule, which certainly has theoretically much in common with the abandoned B. O. M. Rule, should, with some few exceptions, be found to work so well. The only answer I can obtain is really that experience shows with this Rule you get a good

wholesome sea-going yacht, and that experience is a thing which must be set against theory. I know that in every other class of ship we are able to say what is driven, and what is the merit of economy of power in driving it. I have not been able to obtain corresponding information in respect to yachts, and I cannot understand that the Thames measurement does express those quantities.

Mr. Benjamin Martell (Member of Council): I think we are very much indebted to Mr. Dixon Kemp for this Paper, because it deals with the question so thoroughly. It is a subject that he so thoroughly understands, that all the points have been raised and all the difficulties with regard to getting a good law for measurement. But in this new formula that he has placed on the board I see one element which Mr. White has not taken notice of, which seems to me to be the most important—that is the introduction of depth.

Mr. White: I beg your pardon, I asked him that.

Mr. Martell: I thought you said length. We have recently had a great deal to do with this yacht question, and have been considering it with regard to preparing a Register for yachts. I have not had an opportunity of expressing our thanks for the information which we have obtained from Mr. Dixon Kemp on that subject; but the great difficulty would be in knowing where to take our depth. We find on looking over a large number of sections of vessels constructed in that way that there is exceeding difficulty in that. In very fine yachts you find you could make 2 or 3 feet difference where it arises; and where it is so difficult to explain. I think it is a very dangerous element to import, because it may be evaded in so many different ways. I think that is all I should say. I have not read the Paper, but I have looked through it, and I think there are many points that are of great interest.

Mr. John Scott Russell, F.R.S. (Vice-President): My Lord, as far as I understand the subject of yacht building, I think the question of displacement is a much fainter element than it is in any other form of ship. I do not know that displacement enters much into the mind of the man who builds the yacht, or rather who wishes it built. He likes room on board, and that he can get by the two dimensions length and breadth, but it is certain that depth is one great element in yacht sailing, because it is the element of weatherliness, is it not?

Mr. Dixon Kemp: Certainly.

Mr. J. Scott Russell: Weatherliness as distinguished from leewayness. Therefore you might put the problem to a yacht-builder quite in another way. You might say to a yacht-builder, "What is "the least depth you can do with, what is the least beam, and what is the least length?" and you might say that three boats were well matched when those three boats had all of them the same length, all of them the same beam, and all of them the same depth. Now these three elements would be perfectly independent of the element of displacement I think, and I think these three elements would be the main elements of the success of the yacht, and the remaining element about displacement and ballast is only the appendix and the inevitable appendix which remains, and which the skill of the yacht builder could very dodgingly manage. If you will allow me to say so, I made no remark upon those beautiful yacht drawings we had yesterday, because I was obliged to go just at the moment, but I think I never saw more clever dodges in that way than those things we saw in that beautiful collection. I think, therefore, that any formula which takes these three elements into consideration more than any other, does a great deal of good. I did not hear exactly how far the mere displacement does enter into the new formula.

Mr. Dixon Kemp: Not at all.

Mr. J. Scott Russell: Then I am very glad. Then only the three elements of length, depth, and breadth remain?

Mr. Dixon Kemp: That is so.

Mr. J. Scott Russell: Then I am contented. I think that is a very important change, because I think they are the three elements of yacht building.

Mr. Dixon Kemp: With regard to Mr. White's question as to the manner of taking length, as far as my opinion goes on the matter I should say the best plan of taking length would be on the load line; but there appear to be many objections against that, and most of them come under what might be called the head of vested interests, and it is not worth while to allude to them. With regard to the *Columbia's* depth, do you mean with keel down?

Mr. White: Keel down.

Mr. Dixon Kemp: Then her depth may vary from 12 feet to 24 feet according to the portion of board dropped; it is seldom, however, dropped more than 12 feet; the area of breadth multiplied into the

Columbia's length of keel would represent about a foot of depth, as I stated in the Paper. The probable angle of steady heel of the *Columbia* under her canvas in match-sailing would be about 10°, and the *Sea Belle* with a similar wind pressure would be about 18°. But American yachts, if not handled very carefully in strong winds, readily heel to a dangerous angle. I sailed in a yacht in America similar to the *Columbia*, and we had a desperate race from New Bedford, with a strong wind, and the yacht which I and some friends took a passage in laid down so badly in her endeavour to carry sail with the *Cambria*, that she buried herself to the trunk, and they told us we must prepare to go overboard. She was not only hove down but she would not right as she could not be brought head to wind. At last the head sheets were decked, and that relieved her, and that was considered a fortunate circumstance as the mainsail would not have lowered. That is the element of danger in American yachts, that they are enormously stiff up to the time the deck begins to go in, and then they tumble over like the knocking over of a ninepin. Mr. Martell has mentioned the difficulty of obtaining the depth of a yacht. The probability is, if such a Rule as I propose came into operation, the depth would be always taken when the yacht is afloat, and it could be done by simply putting a spar across the rail, with a chain to go under the keel, and then letting the spar and the chain make a triangle, and take the perpendicular of that triangle, which would be the depth. The depth would be taken at equal intervals, and the mean depth could be found by Simpson's Rule. I do not think there would be any difficulty about getting the depth.

Mr. MARTELL: Is it the depth from the bottom of the keel?

Mr. DIXON KEMP: The under side of the keel. There would be this difficulty about it, that a 10-ton yacht now has a width of keel of 10 inches, and that is about the usual width of a yacht of 100 tons.

Mr. MARTELL: If there were a false keel, would you take the false keel?

Mr. DIXON KEMP: Oh! yes, take everything. In fact, you would not only take the keel, but in a boat like the *Jullanàr*, whose model was here yesterday, to get at her main depth you have to take what is submerged abaft the stern-post.

Mr. MARTELL: The difficulty is that a vessel may be built without a false keel, and then her tonnage measured, and immediately after that is done the owner may put on a false keel and the tonnage is altered immediately.

Mr. DIXON KEMP: But somebody would know that—you could not keep a thing like that secret.

CONCLUDING PROCEEDINGS.

The President: Gentlemen, that concludes the business of our Meeting. There are no more Papers, and nothing remains but those complimentary votes which are usually passed to various parties on this occasion, and to which I think we must now direct our attention.

Mr. J. D'Aguilar Samuda, M.P. (Vice-President): I hope I may be permitted on this occasion to express, on behalf of the Meeting, to your Lordship our thanks for your kindness, and for the manner in which you have presided over us on the present occasion. I am quite sure that all the Meeting is fully sensible of the immense advantage that we receive year by year from the kind attention which your Lordship is continually giving us, and that we feel more than ever indebted to you because you thought fit not to allow your own convenience to stand in the way of giving us your valuable attendance at our Autumn Session last year, in addition to the ordinary Session which taxes your time so very heavily, as on the present occasion. May I be permitted to say—and I have no doubt that what I say will be corroborated by the Members present—that we do appear to go on improving year by year in the nature of the Papers which we have put before us and the attendance which we have at our Meetings; and this present Session I think we have occasion to congratulate ourselves more especially, because we know that for the very three days which we have been compelled, in accordance with our usual practice, to hold our Meetings, a similar Institution—the Institution of Mechanical Engineers—had unfortunately fixed their Meetings, and of course to some extent that has interfered with the attendance which many of us desired to give at both places. I need only in conclusion say that many of the Papers are of a very interesting nature, especially Mr. Colin Archer's, and I hope of such a character as will encourage an immediate discussion upon them. It is absolutely necessary that these things should be weighed and thought over; then satisfactory expressions of opinion could be given, such as those who desire to make their opinions useful would like to commit themselves to. It does appear to me, without attempting to go into the consideration of what is put forward in that Paper, that there is a great deal of thought involved in it, and there is a new principle of idea elaborated in that Paper, and it requires a good deal of thinking out before you can say whether it is absolutely correct, or to what extent it can be made useful in future points of construction. I am quite sure that that Paper, in conjunction with many others, and notably one read by Mr. White on the first day, are Papers which, for their practical significance, are of the highest importance; and I hope that at the future Meetings we may have, we may again, in some form or other, be enabled to revert back to those Papers with a view of building up such remarks or observations upon them as the importance of them deserves. I beg to offer to your Lordship the thanks of the Meeting for your kindness.

Dr. Joseph Woolley (Vice-President): My Lord, I have had, I will not say imposed upon me, but offered to me, the extremely pleasing duty of seconding the vote of thanks which has been proposed by Mr. Samuda. Those of us who remember the first formation of this Institution, and who took an active interest in it, will remember how very important we thought it to be to the interests of this Institution to obtain for our first Meeting and subsequent Meetings the presidency of one in whom we could place that reliance in all particulars which it was desirable that we should feel. We looked about to get a gentleman distinguished in the public world if possible, one well known to all in the public world, one who took an active interest in the profession of Naval Architecture, and one who was in such a position that we should all bow to him, as we all have, I hope, always bowed to the decisions of our President. We felt ourselves to be particularly fortunate when it was announced to us by those who had been in search of such a gentleman, that we had the promise of the active co-operation of the gentleman then called Sir John Pakington. We found immediately the advantage of his taking the position of President, and what we found to be good for the Institution in its infant state, we have found equally desirable in its more adult state. I can only say that the noble Lord who now presides over us has always, during the long period of nineteen years, been particularly distinguished by his active co-operation in everything which tended for the interests of the profession of Naval Architecture and a furtherance of the true and proper principles of investigating those questions which are brought before us. We have found the very great value in this Institution of having such a President over us, inasmuch as he has been

enabled on many occasions to place the wishes of this Institution before persons in public positions so as to obtain the carrying into effect of our wishes, which we might not otherwise have been able to attain. I have had the honour of working under his Lordship in another place, and I can say that nobody has ever been brought into contact with him, whether as President of these Meetings or otherwise, but has felt how kind and cordial he has been in the treatment of all who are brought into official communication with him; and we have always felt it a great pleasure to bow to him in every decision of the Chair. I have great pleasure in seconding the vote of thanks which has been proposed by Mr. Samuda.

[The vote was then put to the Meeting, and carried by acclamation.]

The PRESIDENT: Mr. Samuda, Dr. Woolley, and Gentlemen, I can assure you, as I have often assured you before, that I require no thanks, and I fear I deserve very few, for the manner in which I have endeavoured to fulfil my duty as President of this Institution. I have never ceased to take a growing interest in this Institution, and it is a great satisfaction to me at this period, after presiding over it so long, that I think I may without exaggeration say that during the whole of that time this Institution has gradually, from year to year, tended to grow and increase in its utility and its prosperity. Nineteen years have now passed away, as has just been said, since I first had the honour of presiding over this Institution, and I think that I have already told you that the last year was in my opinion the most eventful and the most successful one in every way that we have ever had. I think I may venture to say that, considering the very valuable Papers and Discussions which have distinguished these three days—looking especially to the Discussions with regard to Steel and Iron, and the Discussion we had yesterday morning with regard to the future utility, in its bearing upon Naval Architecture, of the College at Greenwich, and to-day again on other subjects—this Meeting does not yield to any of its predecessors in the importance and interest of the Papers which have been brought forward. Gentlemen, after so long a period as nineteen years, the time cannot be very far off when it will become my duty to express a wish that some younger Member of the Institution may succeed me in this Chair; and whenever that time comes I can only assure you that I sincerely hope and trust I shall leave this Institution in a position of increasing prosperity and public feeling.

Mr. JOHN CORRY (Associate): My Lord and Gentlemen, I have much pleasure in moving that the best thanks of this Meeting be given to the Vice-Presidents, Council, and Officers of this Institution for the great trouble which they have taken in carrying out so successfully the arrangements of this Institution. We are all aware that such matters are not done without a great deal of trouble and forethought, and I think the result of this Meeting shows that that trouble and forethought have been given, and that we have received the benefit of it, and therefore I hope you will give them a cordial vote of thanks.

Mr. HENRY H. WEST (Member): My Lord, Mr Corry has so completely expressed our obligations to the gentlemen referred to in this Resolution that he has left me nothing to say, which is, perhaps, an advantage at this hour. I will only add that I very cordially second the Resolution he has proposed, that a vote of thanks be presented to those gentlemen who have spent so much of their valuable time and thought in ruling over, considering, and arranging our affairs; and particularly would I say that we are under an obligation to the executive Members of the Staff of this Institution, and to them as well as to the Vice-Presidents and Council I beg that this Meeting present a very cordial vote of thanks.

The PRESIDENT: It now becomes my very agreeable duty to put this vote to the Meeting, but I cannot do so without in the first place begging to add to it the assurance of my deep sense of the value of the services of the Vice-Presidents, Council, and Officers of this Institution. I feel very strongly myself that it would have been impossible for me, as your President, to have carried on the affairs of these Meetings for these many years in the way I have been enabled to, if it had not been for the constant, cordial and friendly assistance of the able men who constitute our Vice-Presidents and Officers.

[The vote was then put to the Meeting, and carried by acclamation.]

Mr. E. J. REED, C.B., F.R.S., M.P. (Vice-President): My Lord, I have been requested to respond to this vote on behalf of the Vice-Presidents, and I think I shall best comply with their feeling and their desire by simply saying that we all of us esteem it a high honour to serve under our President, and a very great pleasure to be of any service to the Associates and Members of the Institution.

Mr. HENRY MORGAN (Member of Council): My Lord and Gentlemen, on behalf of those Members of the Council who are not Vice-Presidents I beg to say, without taking up your time at all, ditto to Mr. Reed.

Mr. JOHN SCOTT RUSSELL, F.R.S. (Vice-President): As an old Member of the Society of Arts, I can only say that I think their present governing body, with which I have nothing to do, deserves our most cordial thanks for placing these very noble rooms so kindly at our disposal. I merely would mention that we Members of the Council know how much we are indebted to the Society of Arts, not merely for giving us rooms, but for the cordial way in which they assist us in all our arrangements, and the kind manner in which they place their staff at our disposal. I assure you that the privileges which the Society of Arts give us are privileges which largely economise our funds and greatly increase our strength. I therefore move that a vote of thanks should be given by this Meeting to the Society of Arts for having once more placed their admirable rooms at our disposal, and arranged everything for us in so kindly a manner, in conjunction with our Secretary.

Mr. JOHN R. RAVENHILL (Member of Council): My Lord and Gentlemen, I venture to express the hope that no collision of Meetings may occur again, as unfortunately has occurred during the last two or three days, and I do so for this reason more particularly, that being present last night, a Paper that had been read at the Mechanical Engineers yesterday morning on a most interesting subject was quoted largely in our Discussion. I could not help feeling very sorry that I had been unable to attend and hear them both read and freely discussed. But whilst I lament that, I think we may all go home and feel satisfied with what we have heard here during the last few days. I have only now heartily to second a vote of thanks to the Society of Arts (on behalf of us all) for their kindness in according us the use of this Hall.

[The vote was then put to the Meeting, and carried with acclamation.]

The PRESIDENT: Now, if you will allow me one more word. The paper I hold in my hand contains the different votes which were to be proposed upon this occasion, and which you have now heard; but this paper, as I need not tell you, is, as a matter of form, drawn up by our Secretary, and therefore you will not be surprised that anything like a vote of thanks to our Secretary has been omitted from this paper; but I should be very unworthy of the kind assistance which I have received from our Secretary ever since he was appointed to the office, if I could be capable of forgetting that a vote of thanks is due to him. I am very much obliged to Mr. Woolley for the valuable assistance which he has given us ever since he succeeded our friend Mr. Merrifield in an office so important, and, I may say, so essential to the welfare and success of this Institution, and therefore in the most cordial manner I beg of you to accord a vote of thanks to him for that assistance. I do not think it requires seconding, or thirding, or fourthing. I am sure everybody will with one feeling hold up their hands in favour of the vote of thanks.

[The vote was then put to the Meeting, and carried by acclamation.]

The SECRETARY: My Lord, in thanking you and the Meeting for so kindly passing this vote of thanks, I can only say that I have always endeavoured to do my duty, and that as long as ever my connection with the Institution lasts I will still continue to do so, and I can only hope I shall always give you satisfaction.

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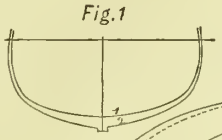
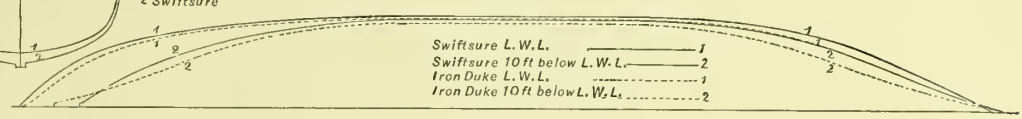


Fig.2



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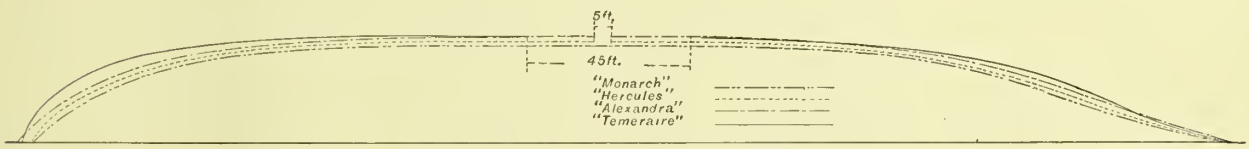
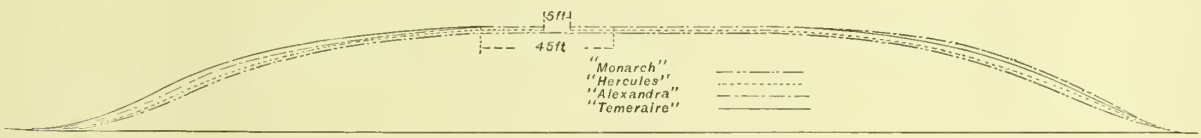


Fig.4



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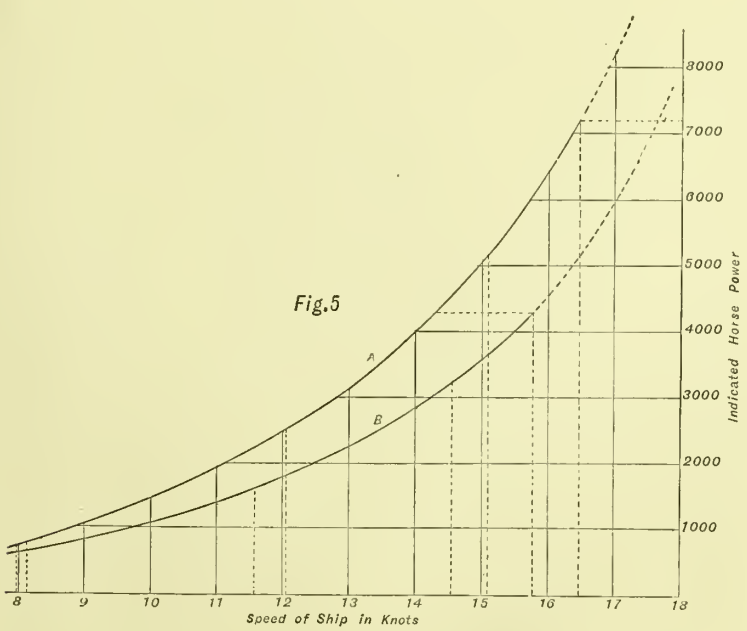


To Illustrate Mr. W. Froude's Paper on the Elementary Relation between Pitch, Slip, and Propulsive Efficiency.

Curves showing, as apportioned between its several elements, the varying energy expended by an oblique propelling plane, driving a ship at constant speed with constant thrust, but with variation of angle of actual pitch (Fig. 3), and of angle of slip (Fig. 4).

Assumed speed of ship 24·2 ft. per second. Assumed thrust, 20,000 lbs. Assumed value of $\frac{f}{p}$ or $k=\cdot005$; ($p=1\cdot7$; $f=\cdot0085$).

Corresponding curves of "efficiency" and of "area of plane necessary" are added.

Ordinate from base to *a a a* = Useful Energy.
,, ,, *a a a* to *b b b* = Energy expended in slip.
,, ,, *b b b* to *c c c* = Energy expended in overcoming longitudinal component of surface friction.
,, ,, *c c c* to *d d d* = ,, ,, ,, ,, transverse ,, ,, ,, ,,
Line { *e e e* is Curve of Efficiency.
f f f ,, Curve of area of plane necessary.

Fig. 3.

Angle of slip (or θ) varying.

Angle of actual pitch (or $[\alpha+\theta]$) constant=45°.

Note.—The latter condition gives maximum efficiency when $\theta=\sqrt{k}$.

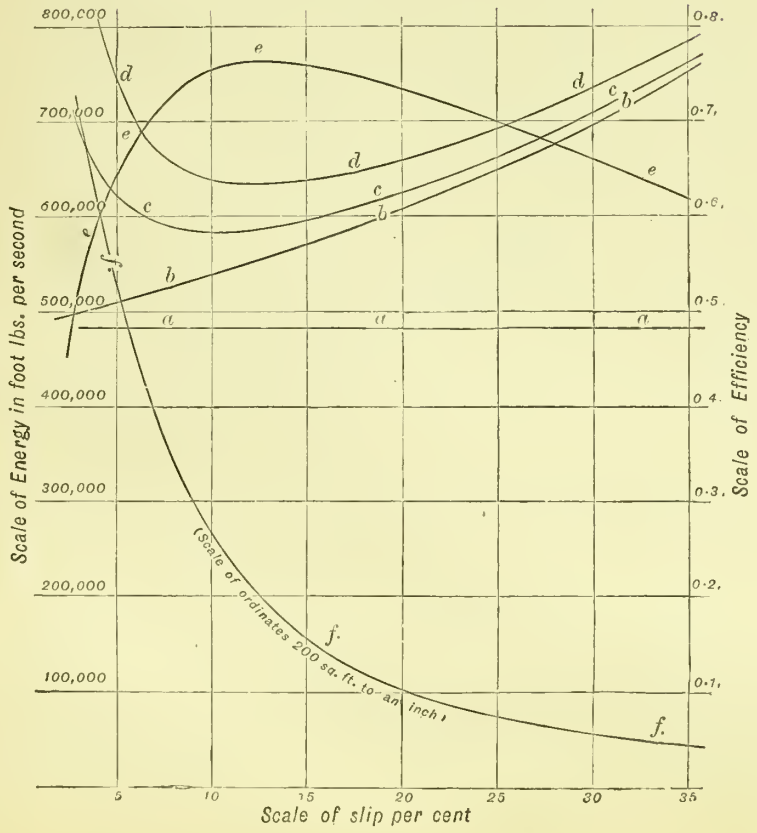
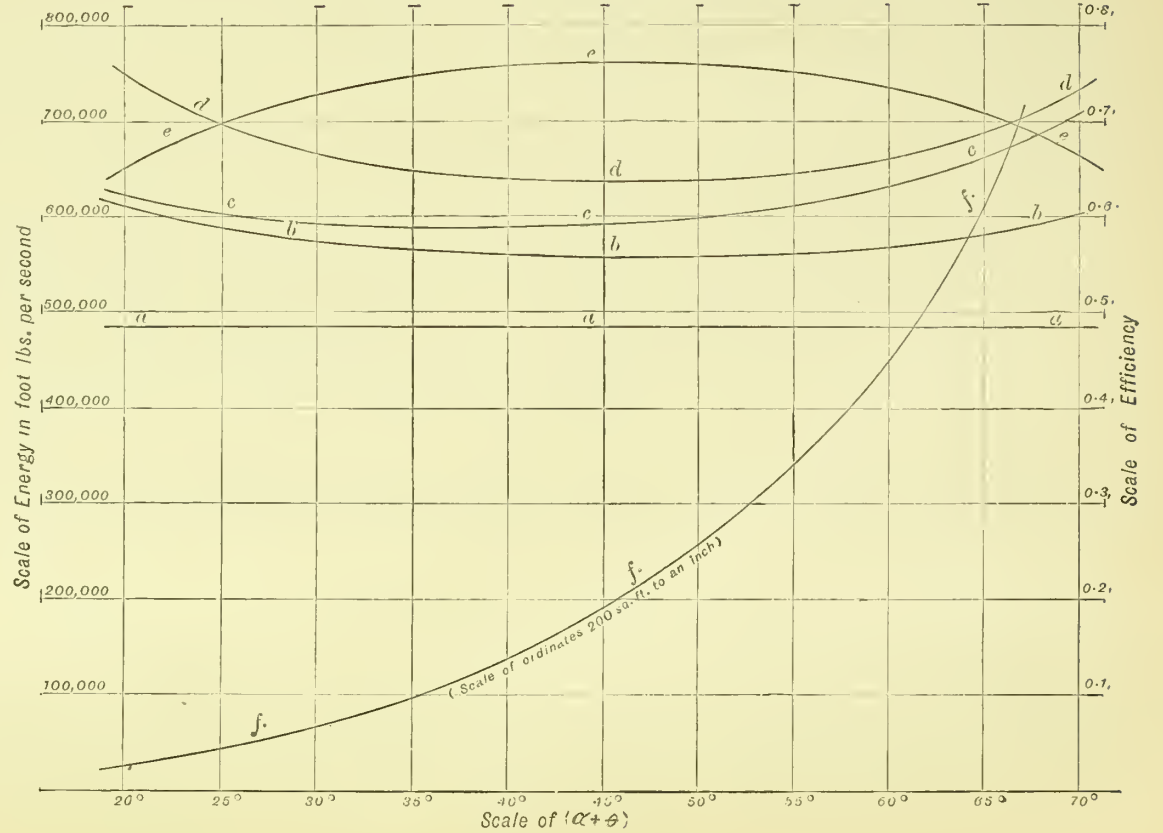


Fig. 4.

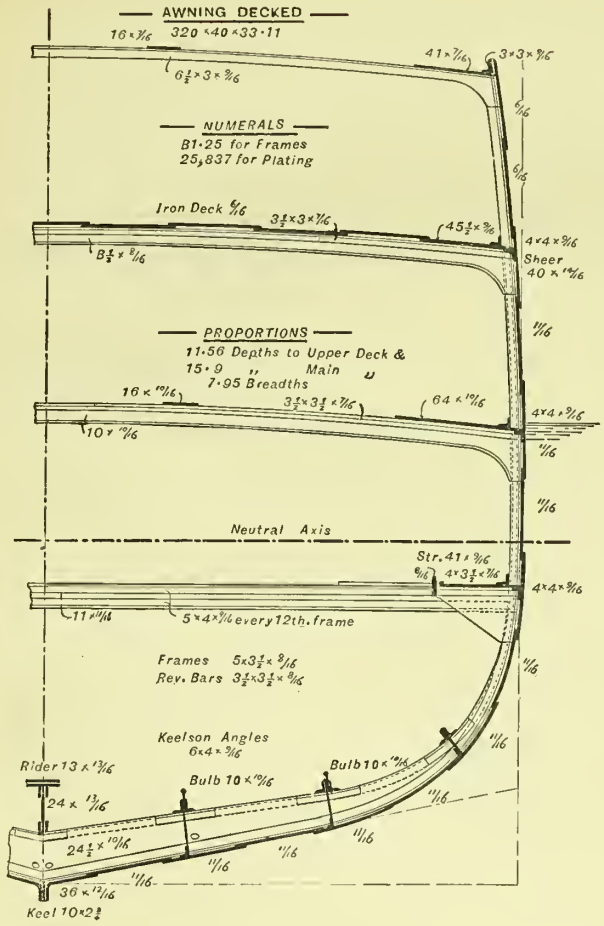
Angle of actual pitch (or $[\alpha+\theta]$) varying.

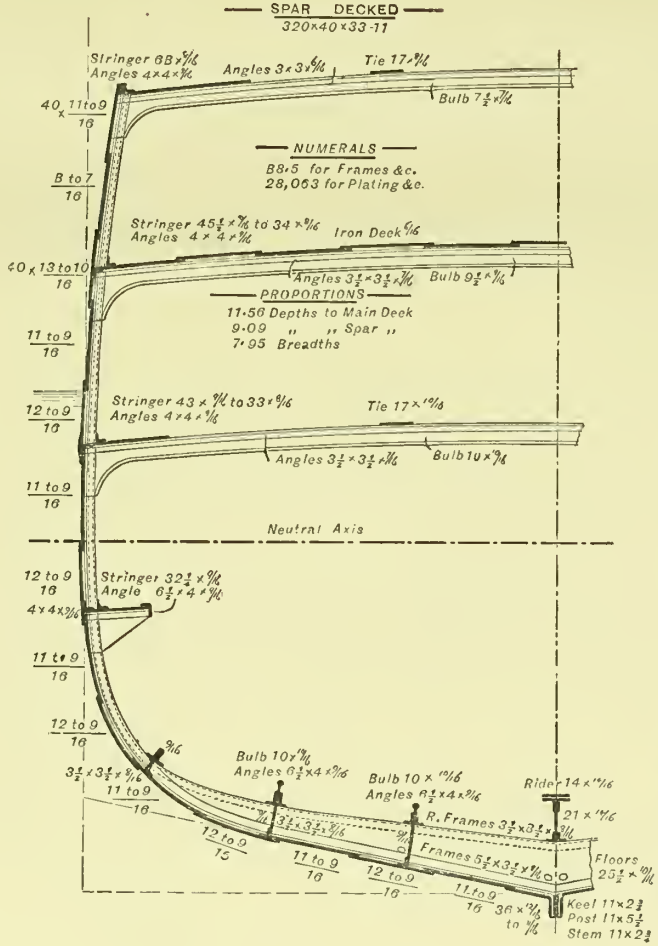
Angle of slip (or θ) constant $=\sqrt{k}$.

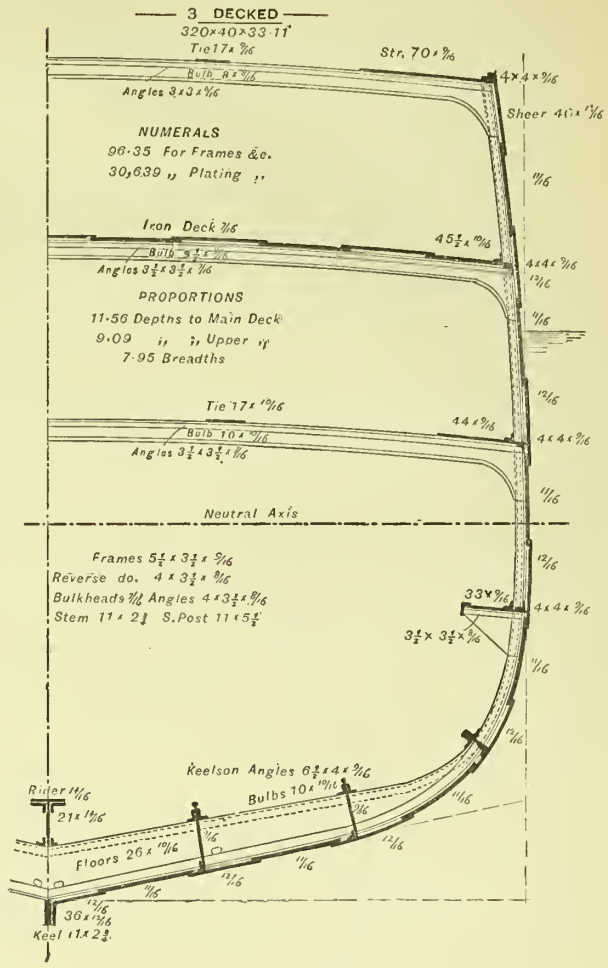
Note.—The latter condition gives maximum efficiency for all values of $[\alpha+\theta]$.



To Illustrate Mr. W. Denny's Paper on Lightened Scantlings.

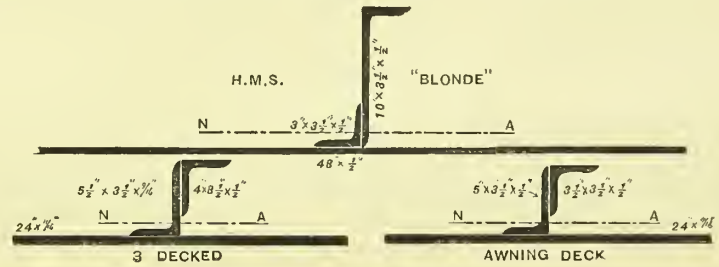






Sections of Plating and Framing taken above the turn of the Bilge for Three-Decked and Awning-Decked Vessels referred to, and from H.M.S. *Blonde*.

	Awning Deck.	3 Decks.	H.M.S. *Blonde*.
Amount of Area in Section, square inches	23·75	24·8	33·5
Value of { Moment of Inertia	15·38	18·7	30·6
Value of { Distance of N A from inner flange of R frame.....			



Dock.

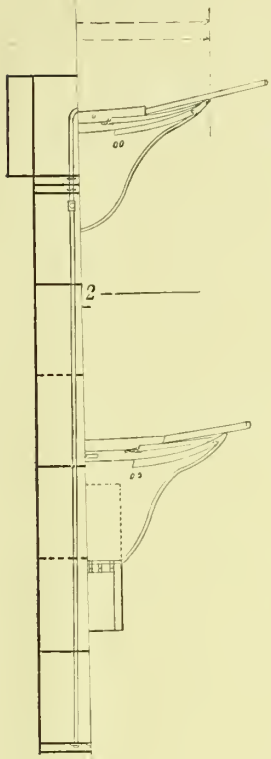


Fig.9

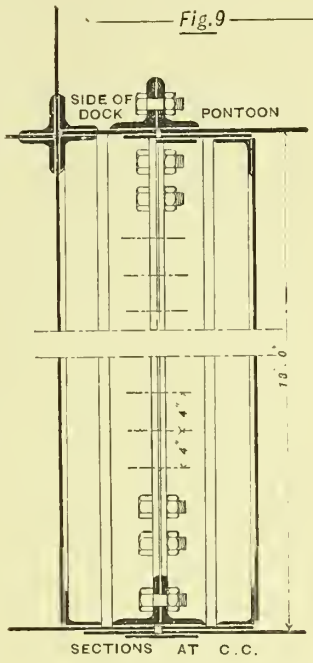


Fig.8

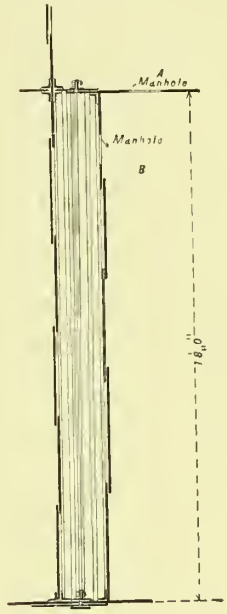
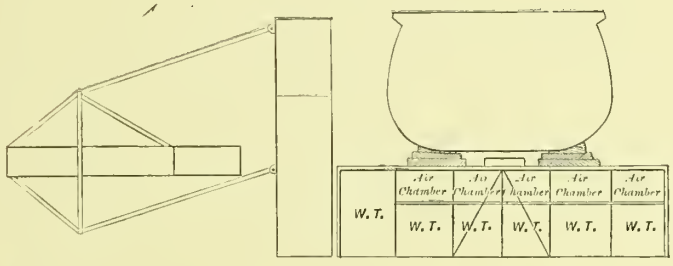


Fig.10



Water

Fig.6

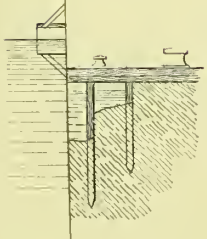
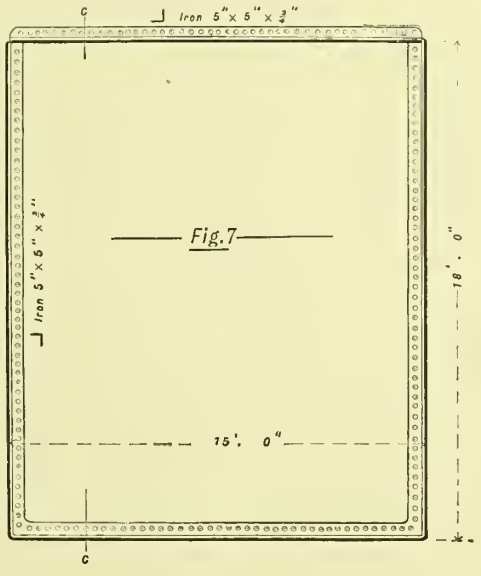
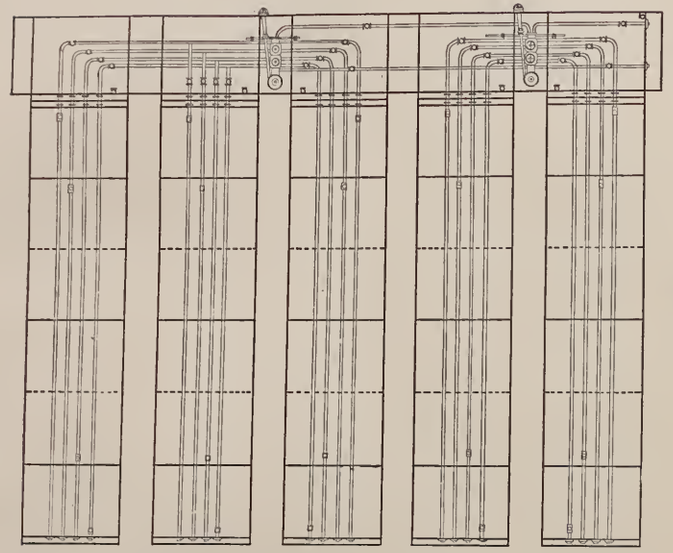


Fig.7



To Illustrate Captain E. E. Goulaeff's Paper on the Nicolaieff Floating Dock.

Fig.11



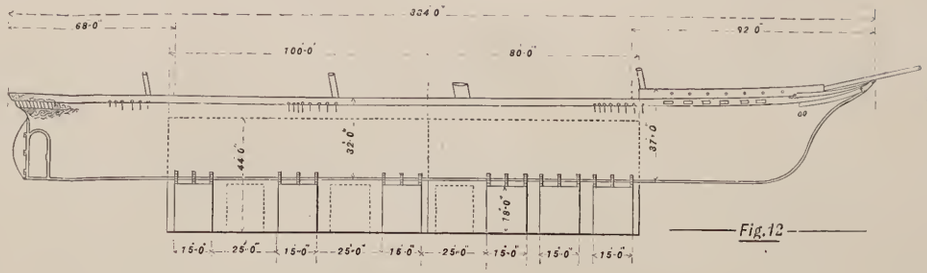


Fig.12

Fig.1

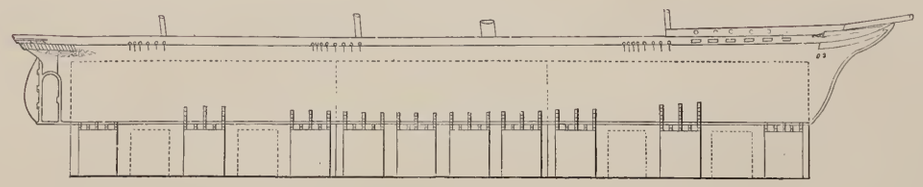


Fig.9

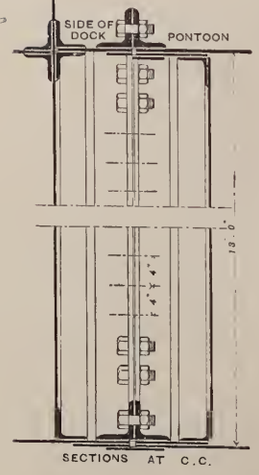


Fig.8

Fig.2

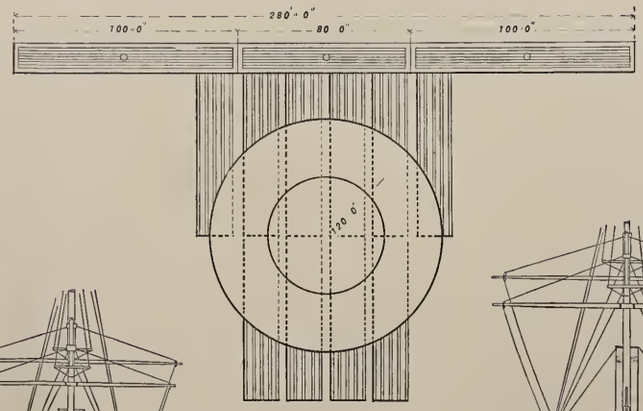


Fig.10

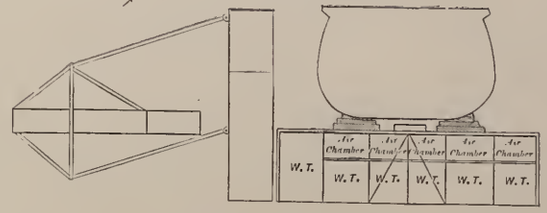


Fig.3

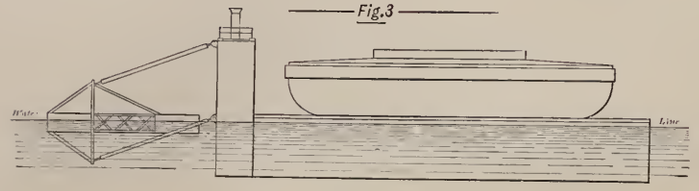


Fig.4

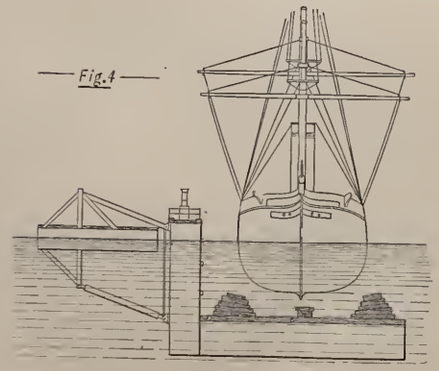


Fig.5

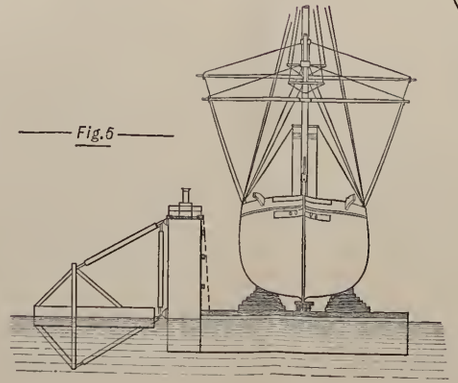


Fig.6

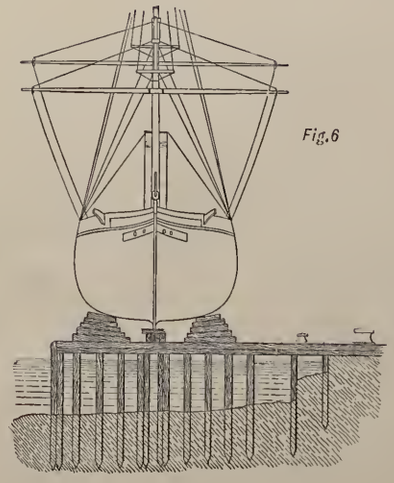
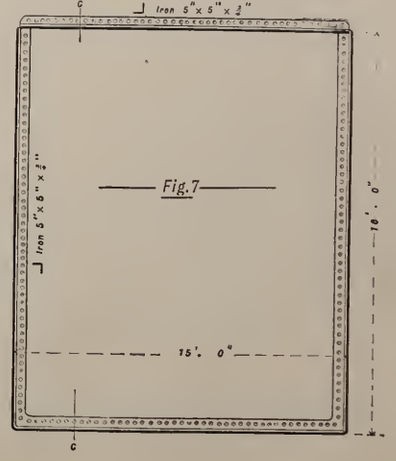
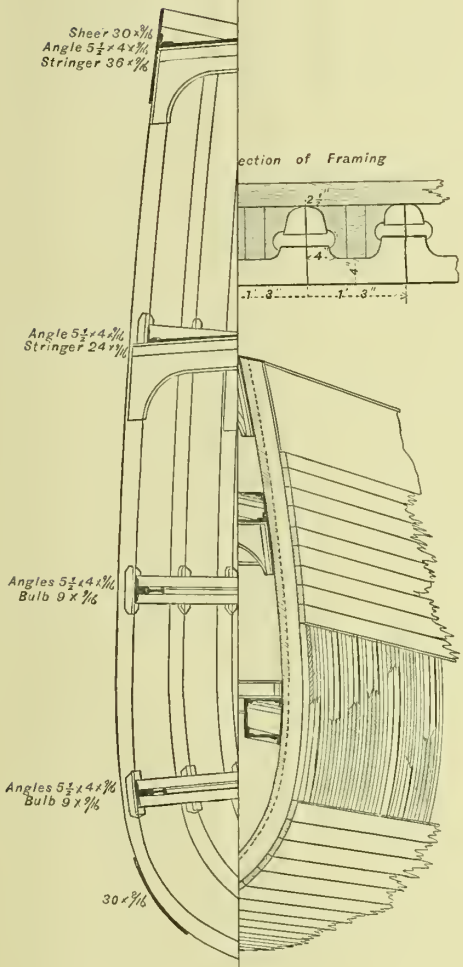
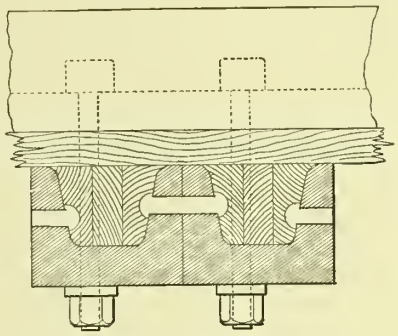


Fig.7

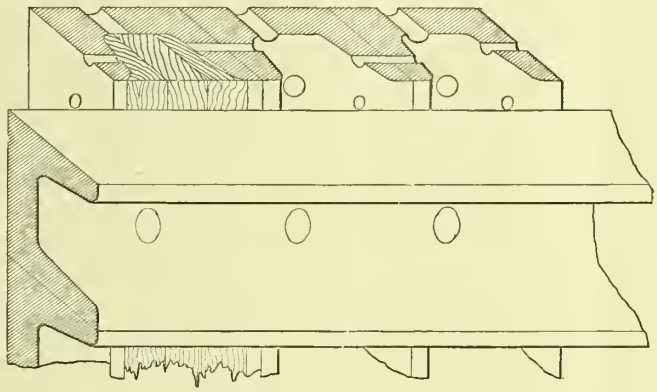


r Iron Ships.

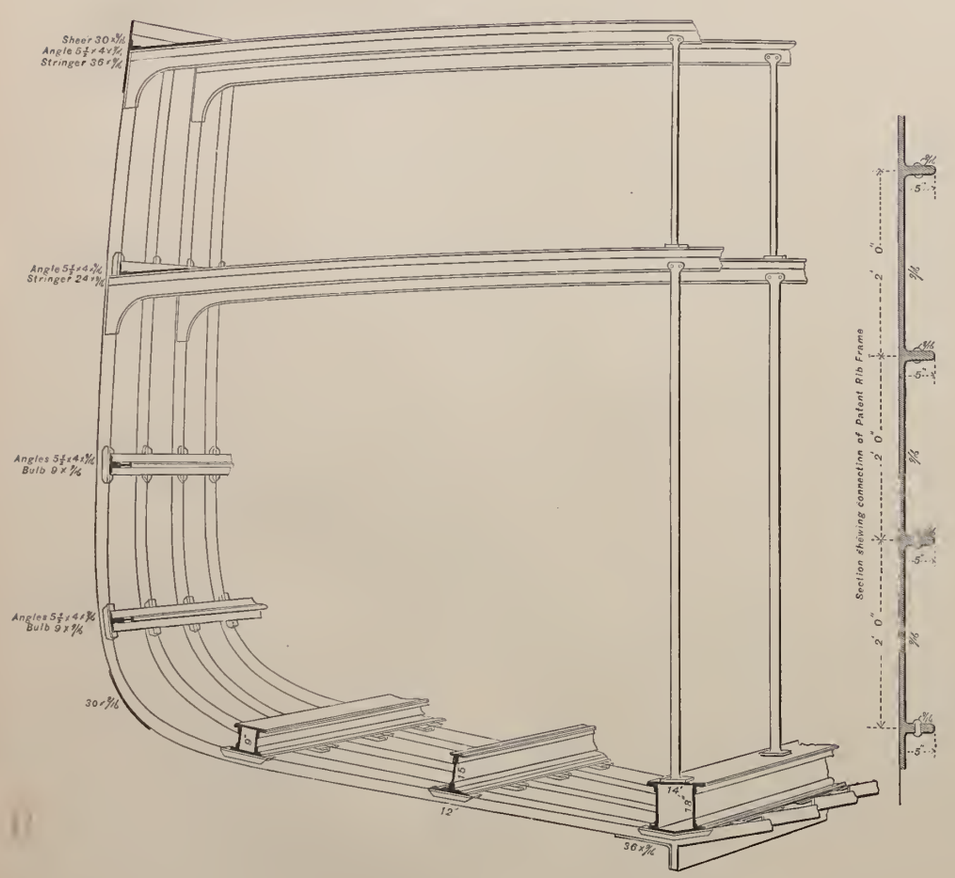

Sheer 30 x 3/16
Angle 5 1/2 x 4 x 3/16
Stringer 36 x 9/16
ection of Framing
2 1/2"
4"
4"
1" 3" 1" 3"
Angle 5 1/2 x 4 3/16
Stringer 24 x 9/16
Angles 5 1/2 x 4 x 3/16
Bulb 9 x 7/16
Angles 5 1/2 x 4 x 3/16
Bulb 9 x 7/16
30 x 9/16

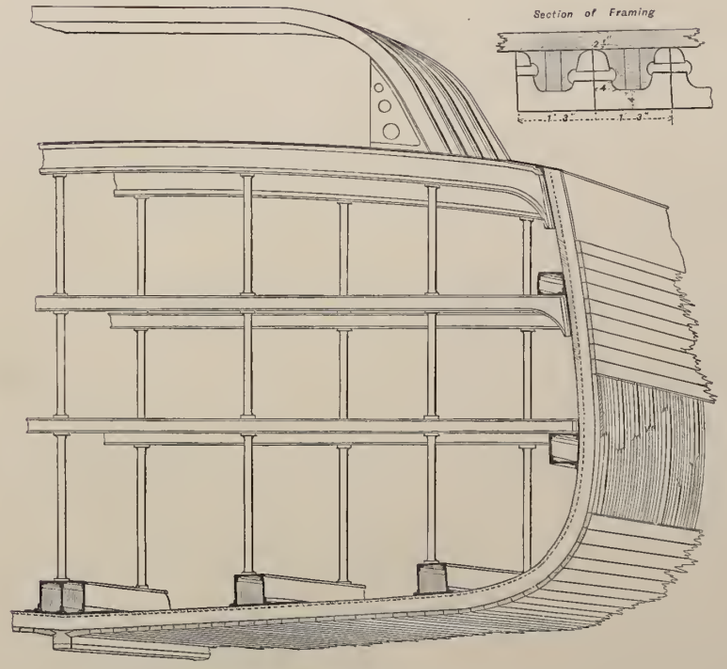


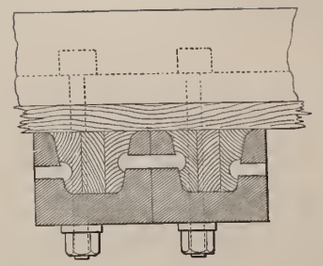
Plan showing adoption of Double Armour.



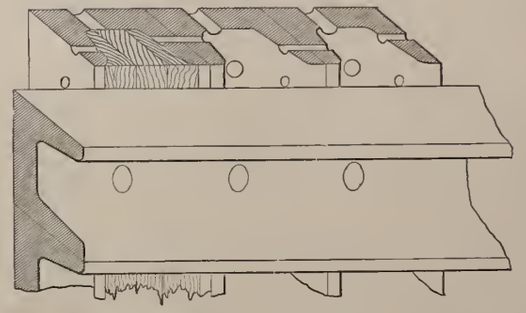
To Illustrate Mr. T. R. Oswald's Paper on a New Principle of Construction for Iron Ships.





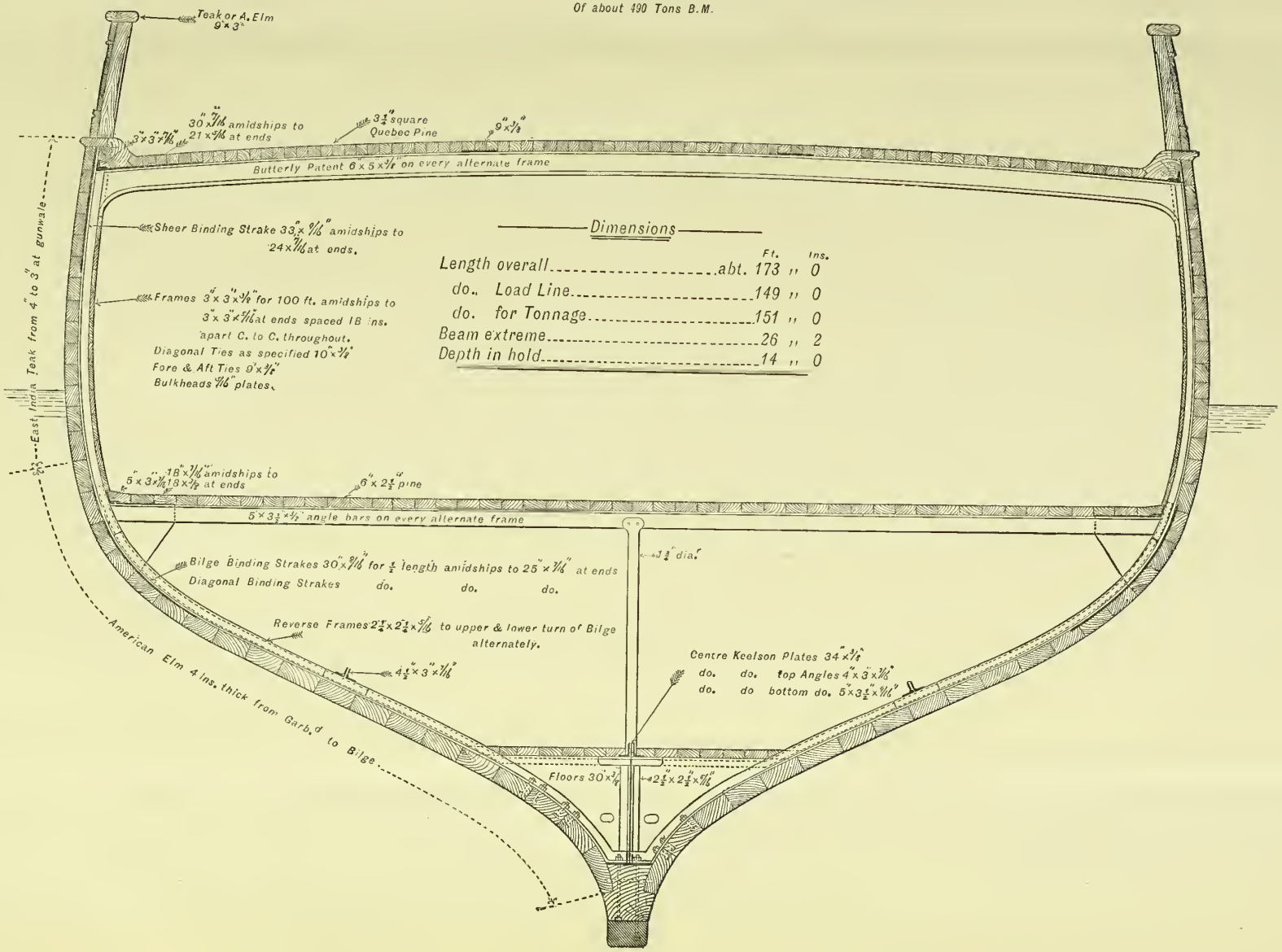


Plan showing adoption of Double Armour.



To Illustrate Mr. St. Clare J. Byrne's Paper on the Construction of Composite Yachts.

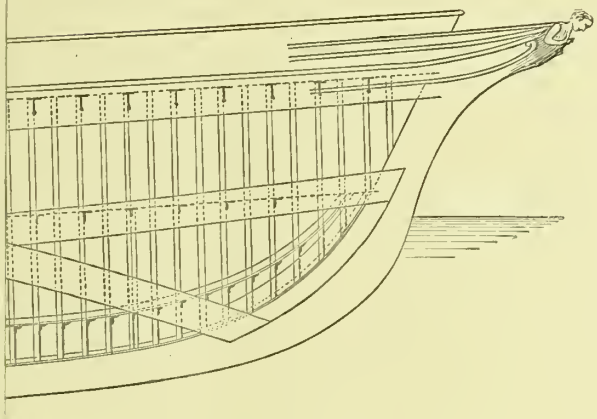
MIDSHIP SECTION
of
COMPOSITE AUXILIARY S.S. YACHT
Of about 190 Tons B.M.

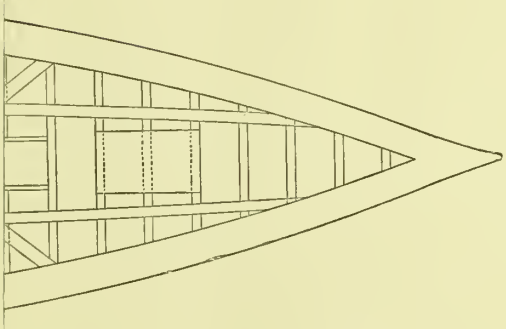

Teak or A. Elm 9"×3"
30"×7/16" amidships to 21"×7/16" at ends
3"×3"×7/16"
3½" square Quebec Pine
9"×1/2"
Butterly Patent 6"×5"×1/4" on every alternate frame
Sheer Binding Strake 33"×9/16" amidships to 24"×7/16" at ends.
Frames 3"×3"×1/2" for 100 ft. amidships to 3"×3"×7/16" at ends spaced 18 ins. apart C. to C. throughout.
Diagonal Ties as specified 10"×1/4"
Fore & Aft Ties 9"×1/2"
Bulkheads 7/16" plates.
East India Teak from 4" to 3" at gunwale
18"×7/16" amidships to 18"×1/2" at ends
5"×3"×7/16"
6"×2½" pine
5"×3½"×1/2" angle bars on every alternate frame
Bilge Binding Strakes 30"×9/16" for ½ length amidships to 25"×7/16" at ends
Diagonal Binding Strakes do. do. do.
1½" dia.
Reverse Frames 2½"×2½"×5/16" to upper & lower turn of Bilge alternately.
4½"×3"×7/16"
American Elm 4 ins. thick from Garb.d to Bilge
Centre Keelson Plates 34"×7/16"
do. do. top Angles 4"×3"×7/16"
do. do bottom do. 5"×3½"×7/16"
Floors 30"×3/4"
2½"×2½"×7/16"

Dimensions

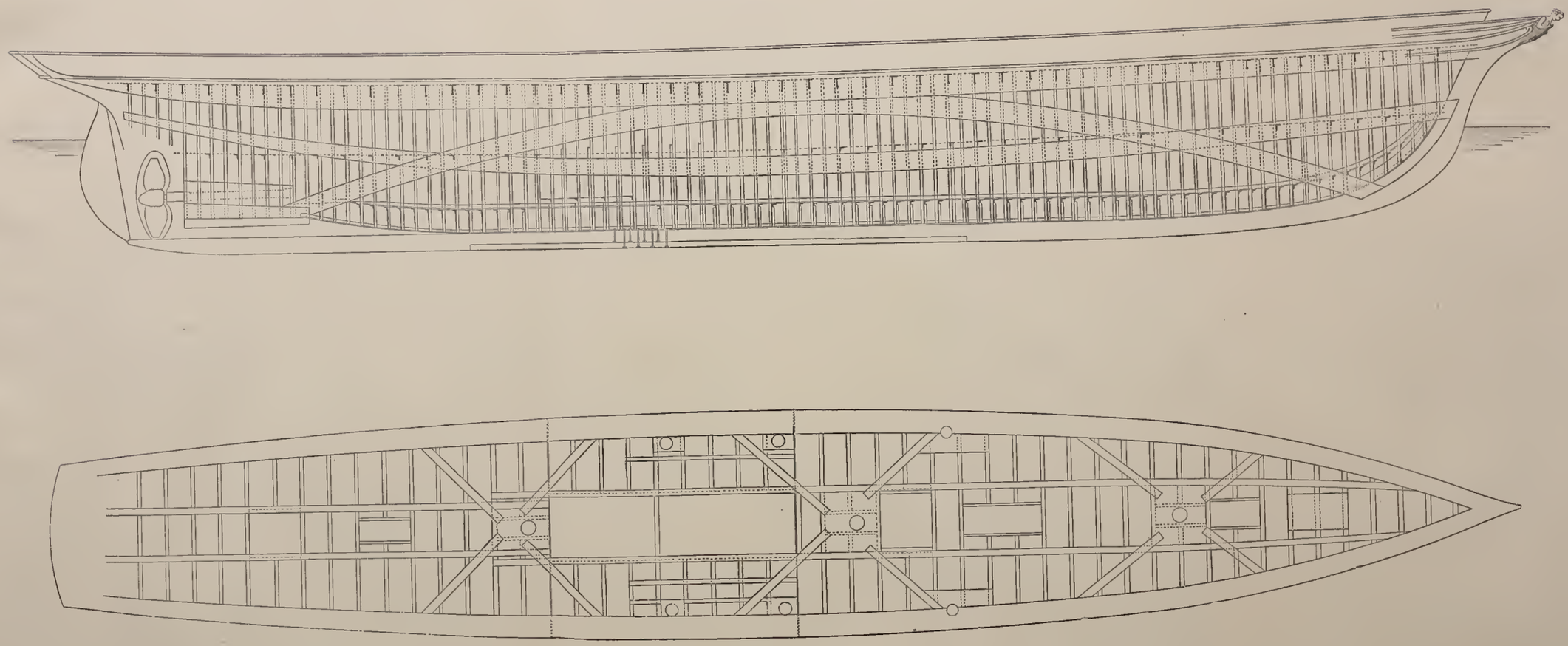
	Ft.	Ins.
Length overall	abt. 173	0
do.. Load Line	149	0
do. for Tonnage	151	0
Beam extreme	26	2
Depth in hold	14	0

Plate VII.





To Illustrate Mr. St. Clare J. Byrne's Paper on the Construction of Composite Yachts.



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